

The Postsecondary Inorganic Chemistry Instructional Laboratory Curriculum: Results from a National Survey

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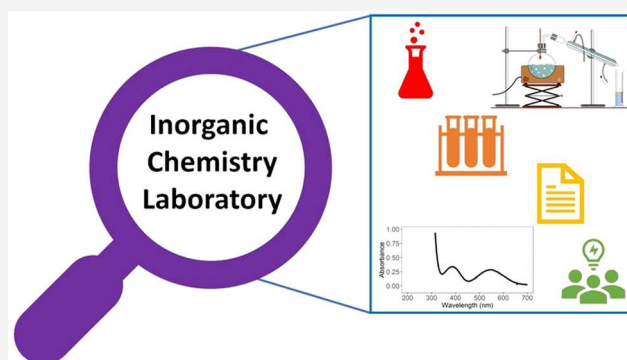
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ABSTRACT: A national survey of chemists ($n = 174$) explored the self-reported format and focus of postsecondary inorganic chemistry instructional laboratory curricula. Multiple instructional laboratory course formats were observed, including stand-alone inorganic chemistry instructional laboratory courses, inorganic chemistry laboratory instruction as a component of a multidisciplinary instructional laboratory course, and the absence of an inorganic chemistry instructional laboratory experience. Additionally, the types of synthetic, characterization, and purification methods, as well as the professional skills addressed in the surveyed courses, varied greatly. The results of this work have direct implications as a “current state of the curriculum” description for inorganic chemistry educators designing and revising instructional laboratory courses. Additionally, these results speak to (1) the need for professional organizations to reinforce the importance of postsecondary inorganic chemistry in the chemistry major curriculum, (2) the demand for quality curricular materials that are easily adaptable to multiple instructional laboratory contexts, and (3) the call for further research on how the inorganic chemistry (and broader chemistry) instructional curriculum is enacted.

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



INTRODUCTION

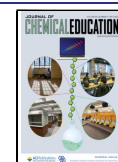
Upper-level instructional laboratory courses, such as those focused on inorganic chemistry, provide a learning context to develop skills and knowledge of the practice of chemistry (i.e., *doing* inorganic chemistry rather than *learning* inorganic chemistry as is the case with lecture courses).^{1,2} Multiple survey research studies of chemistry faculty members were published in 2015 that captured the current state of the inorganic chemistry *lecture course* curriculum.^{3,4} This work documented great variability in terms of the types of inorganic chemistry courses offered and provided the framework for discussion about transforming a inorganic chemistry curriculum.² Parallel evaluations of the undergraduate chemistry curriculum have been reported in this *Journal*; these works focused on building documents for *what* the curriculum could be for each chemistry course by generating a comprehensive list of content coverage⁵ and reviews of summative assessments to determine what content is assessed.⁶ Missing from this body of work are studies focused on lecture-associated instructional laboratory courses or stand-alone instructional laboratory courses. The work reported herein applies the survey methodologies of the inorganic chemistry lecture course studies^{2–4} to capture the current state of the inorganic chemistry instructional laboratory curriculum.

Instructional laboratory courses, for all chemistry subdisciplines, continue to be a focus in the chemical education research community.^{7–14} Most recently, studies have examined the goals faculty members^{7,11} and students^{7,9} have for instructional laboratory courses. In general, faculty members' goals and students' goals are misaligned. Faculty members have “laboratory skills and techniques” and “critical thinking skills and experimental design” as primary goals, whereas students have “completing the laboratory experience quickly”, “feeling good about getting done”, and “earning a decent grade” as primary goals. A key contribution within this body of research on the undergraduate instructional laboratory chemistry curriculum is a study by Bruck and Towns that surveyed faculty members' goals for all chemistry laboratory courses in the United States.¹¹ This is the only example in the literature that has attempted to measure the state of the instructional laboratory chemistry curriculum beyond a single or small set of

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institutions. Given the sampling strategy used, though, the Bruck and Towns study results only captured 132 instructional laboratory courses at the upper level (i.e., not general chemistry or organic chemistry laboratory courses); thus, the findings are limited for upper-level chemistry courses and especially for inorganic chemistry given that an insufficient number of data points were collected for inorganic chemistry laboratory courses to allow for group-level descriptive statistics. In addition, the survey developed by Bruck and Towns¹¹ captured little of the *what*, such as including specifics about course format, of the enacted curriculum in instructional laboratory chemistry courses. The work we report addresses these issues of sampling and scope. While the 174 courses sampled in our study is on the same order of magnitude as the Bruck and Towns study ($n = 132$), recall that our study is focused on inorganic chemistry instructional laboratory courses whereas the Bruck and Towns study sampled instructional laboratory courses from all chemistry subdisciplines. Thus, our sample is more representative of the inorganic chemistry laboratory course population.

We expect to observe in our study a variability in the inorganic chemistry instructional laboratory course curricula similar to that reported for the inorganic chemistry lecture course curriculum.^{2–4,6,15} The results of this work provide an opportunity to consider how to further transform and improve the inorganic chemistry laboratory course and the broader undergraduate chemistry curriculum. Members of the Leadership Council of the Interactive Online Network of Inorganic Chemists (IONiC; of which multiple authors of this work are members)^{16,17} are routinely asked “What should I be teaching in my instructional laboratory course?” While there is no single “correct” answer to that question, a descriptive account of the course, as it is enacted at a range of institutions, can provide valuable information for an instructor to make decisions when creating new laboratory courses or adding new laboratory experiments to an existing course. Similarly, a descriptive account of the current course has the potential to inform organizations such as the American Chemical Society’s Committee on Professional Training when developing guidelines for degree programs and for departments considering revising their degree program curricula.¹⁸ Lastly, a “current state” documentation of the curriculum provides educational researchers with a starting point from which to consider the evolution of the chemistry curriculum across time. Such accounts inform researchers as to the population of instructional laboratory courses from which to conduct more detailed investigations of learning, enacted curriculum, and instructional practices.⁸

PURPOSE

The purpose of this study was to provide a broad description of the undergraduate inorganic chemistry instructional laboratory curriculum. This study complements two prior survey research studies on the inorganic chemistry lecture course curriculum^{3,4} as well as parallel survey research studies on the enacted curriculum across undergraduate chemistry courses.¹⁹

METHODS AND SAMPLE

The study was reviewed and approved by the University of South Florida’s Institutional Review Board on September 24, 2019 (Application Pro00042058).

Registered faculty member users ($N = 1,467$) of the Virtual Inorganic Pedagogical Electronic Resource (VIPeR)¹⁶ website and faculty members of the Division of Inorganic Chemistry of the American Chemical Society ($N \approx 6,000$) were invited via email to complete the survey in October 2019; a reminder email was sent 2 weeks later (early November 2019). Data were collected anonymously without personally identifiable information. Given the convenience sampling method, we caution against over interpretation of the results; however, given the methods employed and due diligence data collection, the results of the survey provide a foundation and starting point for characterizing inorganic chemistry laboratory courses within the United States.

A total of $n = 328$ respondents opened the survey with $n = 314$ beginning the survey, $n = 294$ providing consent to participate, and $n = 239$ providing information about the inorganic chemistry laboratory curriculum at their institution.

Twenty-seven survey items (see the [Supporting Information](#)) related to the inorganic chemistry instructional laboratory curriculum were administered to each respondent; note that not all respondents saw every question (e.g., if respondents did not report students working in groups, then that respondent did not see the related follow-up question). Survey questions were informed by previous work analyzing the inorganic chemistry lecture curriculum,^{2–4} the American Chemical Society’s Committee on Professional Training’s Supplement on the Inorganic Chemistry Instructional Laboratory Curriculum,^{18,20} an IONiC workshop discussion with inorganic chemistry educators, as well as discussions with the Leadership Council of IONiC (i.e., faculty members with expertise in teaching inorganic chemistry). Questions focused on characterizing the types and structures of inorganic chemistry lab courses; the various synthetic, purification, and characterization methods employed; as well as the classes of materials synthesized and the professional skills that instructors would like students to develop. Additionally, given the study’s focus on the laboratory curriculum, some items also addressed student choice/freedom in the lab, as informed by the rubric for characterizing inquiry in undergraduate laboratories by Bruck, Bretz, and Towns¹⁴ as well as on the use of embedded research experiences within laboratory courses. Except when necessary for survey logic (i.e., responses needed to determine if other survey items should be shown or not shown), respondents were not required to respond to an item; therefore, n -values vary (and are thus noted) for each survey item.

Of the 239 respondents providing information about the inorganic chemistry laboratory curriculum at their institution, 59% are from institutions where a bachelor’s degree in chemistry/biochemistry is the terminal chemistry degree, 8% are from institutions where a master’s degree in chemistry/biochemistry is the terminal chemistry degree, and 22% are from institutions where a doctorate degree in chemistry/biochemistry is the terminal degree; 11% of respondents did not provide this information. This distribution mirrors the representation of chemistry/biochemistry terminal degree programs in the United States.¹⁹

Of the 239 respondents, 72% are from institutions that offer an ACS-certified bachelor’s degree in chemistry¹⁸ and 15% are from institutions that do not offer an ACS-certified bachelor’s degree in chemistry; 13% of respondents reported “I don’t know” or did not provide this information.

Table 1. Variations of Inorganic Chemistry Instructional Laboratory Curricula

variation	I	II	III	IV	V	VI	VII	VIII	IX	X
<i>n</i> (%) =	19 (9%)	82 (37%)	81 (37%)	38 (17%)	7 (3%)	4 (2%)	3 (1%)	2 (1%)	2 (1%)	1 (0%)
No inorganic chemistry laboratory course	X									
One stand-alone/independent inorganic chemistry laboratory course		X				X			X	
Two or more different independent inorganic chemistry laboratory courses					X			X		X
The inorganic chemistry laboratory course is incorporated into an inorganic chemistry lecture course			X				X	X	X	X
Inorganic chemistry-focused syntheses, characterization, and laboratory techniques are integrated into a course that includes other subdisciplinary foci (e.g., analytical or physical)				X		X	X			X

Of the 239 respondents, 83% self-identified with the inorganic chemistry subdiscipline, 16% with the materials chemistry subdiscipline, 6% with the education research subdiscipline, and 5% with the teaching practice subdiscipline.

Finally, of the 239 respondents, 66% were tenured, 17% were on a tenure track but not tenured, 3% were not on a tenure track but at an institution with a tenure system, and 2% were at an institution that does not have a tenure system; 12% of respondents did not provide this information.

RESULTS AND DISCUSSION

Descriptive statistics are presented for each survey item. Participants were asked to respond to the survey items in reference to a single undergraduate inorganic chemistry instructional laboratory course taught in the last three years over which they felt they had the most control; thus, results reflect the most ideal context in which the respondents are enacting their instructional laboratory curriculum.

Inorganic Chemistry Instructional Laboratory Curriculum

Unlike gateway chemistry courses (i.e., general chemistry and organic chemistry), the inorganic chemistry laboratory curriculum is highly variable including independent courses, courses integrated with inorganic chemistry lecture courses, and inorganic chemistry focused instructional laboratory experiences incorporated into multisubdisciplinary instructional laboratory courses. These variations parallel the variability observed in inorganic chemistry lecture courses.^{2–4}

Respondents were asked to select all statements that best describe the inorganic chemistry laboratory curriculum at their institution. Eighty-eight total respondents have one stand-alone course, 89 total respondents have an integrated lecture/laboratory course, 46 total respondents have inorganic chemistry laboratory experiences integrated into a broader instructional laboratory course, 10 total respondents have two or more stand-alone courses, and 19 respondents had no inorganic chemistry laboratory course at their institution.

A reader should be cautious about extrapolating corresponding percentages to these numbers in trying to make claims about the “percentage of chemistry degree programs that have ‘X’ inorganic chemistry laboratory courses” as the limited sampling strategy has potentially large associated error; a reader might better conclude that, for example, “there is a discernible number of chemistry degree programs that lack any inorganic chemistry laboratory course” or “that an integrated lab-lecture inorganic chemistry course or a stand-alone inorganic chemistry laboratory course are the most likely inorganic chemistry laboratory curricula”.

Respondents could select all that apply, and thus, 10 combinations of courses were reported (see Table 1). For

example, while 88 total respondents reported one stand-alone laboratory course, this was the *only* inorganic chemistry laboratory course (Variation II in Table 1) for 82 of those respondents; for four of those respondents there is also an instructional laboratory course that integrates inorganic chemistry (Variation VI in Table 1); and, for two of those respondents, there is also an integrated inorganic chemistry lecture/laboratory course (Variation IX in Table 1). In total, 19 respondents reported more than one instructional laboratory course that was focused on or included inorganic chemistry (Variation V through Variation X in Table 1).

Of the 220 respondents who reported some form of an inorganic chemistry instructional laboratory curriculum, 81 reported having taught a stand-alone inorganic chemistry laboratory course in the last three years and 93 reported having taught an integrated laboratory and lecture course on inorganic chemistry in the last three years (see Table 1). These 174 respondents are the focus of the remainder of our analyses; this choice was made as data were collected about a specific course. If respondents had not taught the course, they are unable to answer; if respondents had not taught the course recently, they may not sufficiently recall the specifics of the course.

Pre- and Co-requisite Courses for the Inorganic Chemistry Instructional Laboratory Course

Respondents were also asked to select which of nine courses were a pre-/co-requisite course for their inorganic chemistry instructional laboratory course (see Table 2). General chemistry and organic chemistry courses were reported as pre-/co-requisite courses for over half of the respondents; this parallels the pre-/co-requisite courses reported previously for inorganic chemistry lecture courses.² Nearly a third have

Table 2. Distribution of Pre- and Co-requisite Courses

course	<i>n</i>	pre-/co-requisite course (%)	not a pre-/co-requisite course (%)	not offered at their institution (%)
General Chemistry	158	93	6	1
Organic Chemistry 1	156	75	25	
Organic Chemistry 2	153	65	35	
Foundations Level Inorganic Chemistry	140	48	41	11
Physical Chemistry – Thermodynamics	143	33	66	1
Analytical Chemistry	139	31	65	4
Physical Chemistry – Quantum Mechanics	141	28	71	1
In-Depth Level Inorganic Chemistry	135	13	56	31
Biochemistry	132	2	97	1

physical chemistry (both thermodynamics and quantum mechanics) and analytical chemistry as a pre-/co-requisite course. This finding is congruent with the “integrated” laboratory curriculum that institutions are offering as an “upper-level” instructional laboratory course rather than offering individual subdisciplinary laboratory courses.¹⁸ Collectively, the results of Table 2 suggest that placement of the inorganic chemistry laboratory course is highly variable by institution.

Characteristics of the Inorganic Chemistry Instructional Laboratory Course

Respondents ($n = 160$) were asked to report the number of students typically enrolled in their course using a dropdown menu with options ranging from 1 student to 50+ students; 3 respondents selected 50+ students. Of the remaining 157 respondents, the average number of students enrolled is 12 students with a standard deviation of 9 students and a median of 10 students. Unlike general chemistry and organic chemistry courses (even at small institutions), few students take both lecture and laboratory inorganic chemistry courses.^{2–4} This is, in part, due to these courses being required for chemistry degree programs only, whereas general chemistry and organic chemistry are requisite courses for many STEM disciplines and are elective science/laboratory courses for a wide range of degree programs. These small course enrollments can provide an environment suitable for managing more research-based instructional laboratory experiences. We should note, however, that such experiences are not prohibitive on a larger scale as has been shown, for example, through course-based undergraduate research experiences implemented across the undergraduate laboratory curriculum.^{21–23}

Respondents were also asked how often their course was taught ($n = 161$): 70% “once a year”, 24% “every-other year”, 6% “every semester”, and 1% “as needed” (note: percentages do not add up to 100% due to rounding). Given the small enrollment in inorganic chemistry laboratory courses, it is not surprising that the courses are taught less frequently.

Respondents were asked how many days per week their course met ($n = 160$): 80% “1 day”, 16% “2 days”, 4% “3+ days”. Respondents were asked how many hours per class meeting were students engaged in laboratory activities ($n = 155$): mean = 3.5 h, SD = 1.0, minimum = 1, and maximum = 8.

Respondents indicated how many distinct/individual experiments students conduct in their course ($n = 159$) with a dropdown menu from 1 to 17+; 1 respondent chose 17+. Of the remaining 158 respondents, the average number of experiments is 7.3 with a standard deviation of 2.7 experiments and a median of 7 experiments. Assuming a 10-week quarter-system term and a 15-week semester-system term, each experiment ranges from slightly more than one experiment per week to one experiment every 5–7 weeks. On average, the number of experiments suggests that most experiments last more than 1 week. Again, this points to more complex, time-consuming experiments than what have been reported for “traditional” general chemistry instructional laboratory experiments.¹⁴

Respondents were also asked about the participation of teaching assistants and other instructional staff that supported their course ($n = 154$): 59% reported “no TAs are used”, 19% used graduate teaching assistants, 16% used undergraduate teaching assistants, and 11% used “other non-TA support”

staff. Note that responses are not independent; four respondents used undergraduate TAs and non-TA support staff, three respondents used graduate TAs and non-TA support staff, one respondent used graduate and undergraduate TAs, and one respondent used graduate and undergraduate TAs as well as non-TA support staff. With almost two-thirds of respondents reporting “no TAs are used”, we can conclude that the majority of inorganic chemistry laboratory instruction is being done without the assistance of teaching assistants and support staff.

How Students Work in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked how their students complete experiments in their inorganic chemistry instructional laboratory curriculum (see Table 3). Responses were not mutually

Table 3. Student Work ($n = 163$)

	<i>n</i>	%
Students work in pairs	118	72
Students work individually	72	44
The entire class works collaboratively together	42	26
Students work in groups of 3–5	31	19
Students are able to work outside of normal lab time (e.g., an “open lab” policy)	22	13

exclusive. Almost three-quarters of respondents reported students working in pairs. Nearly half of the respondents reported having their students complete experiments individually as well.

Format of Laboratory Experiments in the Inorganic Chemistry Instructional Laboratory Course

This survey item is a modification of an inquiry rubric by Bruck, Bretz, and Towns that has been used to evaluate instructional laboratory experiments in STEM.¹⁴ The original rubric was designed to evaluate individual laboratory experiments on the inclusion of six activities, with the laboratory experiment allowing for or not allowing for each of the six activities. The activities are hierarchical, with a final rating based on how many of the activities were included within an instructional laboratory experiment. The original rubric suggested that if an instructional laboratory experiment included all six activities, then the experiment was an inquiry-based experiment. We re-envisioned the rubric as a set of items that evaluated the percentage of the laboratory experiments that engaged students in each of the six activities, with higher percentages interpreted as a more inquiry-focused instructional laboratory course. Results are reported in Table 4.

With 87% of respondents stating that students can “determine and interpret the conclusions of the experiment” on their own, our results parallel Bruck, Bretz, and Towns results on a broad array of STEM instructional laboratory experiments.¹⁴ At the other end of the spectrum, 15% of respondents stated that students were able to choose the problem or question to be investigated. This is higher than has been typically reported for most STEM instructional laboratory experiments; however, this result tracks with upper-level STEM laboratory courses where more multiweek, research-based experiments are used in instruction.¹⁴ Lastly, it is important to note the anomaly in these results: 52% of respondents stated that students had to look up and research the theory or background behind the investigation. The rubric

Table 4. Format of Laboratory Experiments ($n = 159$)

	mean %	SD	min	max
Determine/interpret the conclusions for the experiment	87	22	0	100
Choose how to communicate their results/conclusions	36	37	0	100
Choose how to analyze their results	34	32	0	100
Choose what procedures/designs to use to investigate the problem	22	27	0	100
Look up/research the theory or background behind the investigation	52	35	0	100
Choose the problem or question to be investigated	15	18	0	100

Increasing
level of
inquiry
↓

as conceived by Bruck, Bretz, and Towns¹⁴ is a Guttman-type scale,²⁴ where in each successive level of increasing inquiry all previous statements are true. Thus, if students were allowed to choose how to communicate their results, then the students also determined the conclusions for the experiment. We should therefore see decreasing percentages at each successive level of inquiry; however, the “theory and background” option does not trend as expected. Our hypothesis is that this finding represents the importance that the primary literature has in upper-level courses, including literature discussions used as classroom activities for teaching concepts and skills in such courses.^{1–4,25}

Sources of Laboratory Experiments in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to report which of five sources (select all that apply) were used to find/develop experiments for their laboratory course (see Table 5). Over 9 out of 10 respondents

Table 5. Sources of Laboratory Experiments ($n = 151$)

	n	%
<i>Journal of Chemical Education</i>	140	93
Developed by yourself at your institution	113	75
Virtual Inorganic Pedagogical Electronic Resource (VIPeR) website	104	69
Textbooks	91	60
Developed by colleagues at your institution	39	26

stated that the *Journal of Chemical Education* was the source of laboratory experiments used in their courses; this finding reinforces the importance of this Journal as a repository of laboratory experiments. Three-quarters of respondents developed their own laboratory experiments. Nearly 70% utilized the VIPeR website¹⁶ as a laboratory experiment resource; we caution that this finding may be high due to our sampling strategy. Nevertheless, this reinforces the importance of the VIPeR website as an important repository of laboratory experiments. Textbooks serve as a laboratory experiment resource for 6 out of 10 respondents. Finally, approximately a quarter of respondents use laboratory experiments developed by their colleagues.

Structure of Laboratory Experiments in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to estimate the percentage of experiments in their course in which students engage in activities as individuals (see Table 6) and in groups (see Table 7; note: options are not mutually exclusive and 0% through 100% were reported for every structure type). For both individual and group completion of experiments, the most frequent structure is for students to be conducting experiments

Table 6. Structure of Laboratory Experiments for Individual Students ($n = 77$)

	mean (%)	SD
Students conduct the same experiment at the same time	64	30
Students conduct related experiments at the same time and share/collaborate results with other students and/or the whole class	36	25
Students select laboratory experiments from a collection of options (not every student conducts the same experiments throughout the semester)	25	25
Students rotate through experiments/stations throughout the semester (every student conducts every experiment, but at different times)	23	30

Table 7. Structure of Laboratory Experiments for Student Groups ($n = 126$)

	mean (%)	SD
Groups conduct the same experiment at the same time	65	33
Groups conduct related experiments at the same time and share/collaborate results with other groups and/or the whole class	45	32
Groups rotate through experiments/stations throughout the semester (every group conducts every experiment, but at different times)	32	33
Groups select laboratory experiments from a collection of options (not every group conducts the same experiments throughout the semester)	26	29

at the same time, followed by time for collaborating and aggregating results. Selection from a collection of options or rotation through laboratory stations were the least frequent structures. Overall, the most common structure of inorganic chemistry laboratory courses is that students, individually or in groups, are completing the same experiment at the same time.

Emphasis of the Inorganic Chemistry Instructional Laboratory Course

Four areas of emphasis are recommended in the Committee on Professional Training's Supplement on the Inorganic Chemistry Instructional Laboratory Curriculum:²⁰ (1) synthetic methods, (2) purification methods, (3) characterization methods, and (4) professional skills. Respondents were asked to rank these areas from most to least emphasized in their inorganic chemistry instructional laboratory curriculum (see Table 8). Synthetic methods and characterization methods were reported as being most emphasized in the courses, with purification as the third most emphasized, and professional skills the least emphasized. It should be noted that this item asked respondents to rank the relative level of importance; these results do not suggest that professional skills, for example, are not taught, but rather that professional skills are

Table 8. Level of Emphasis for Key Content Areas ($n = 167$)

levels of emphasis	most (5)	(4)	(3)	(2)	least (1)
Synthetic methods	92	32	26	16	1
Characterization methods	52	84	22	9	0
Purification methods	1	12	42	100	12
Professional skills	4	5	4	4	150

the least ranked emphasis in the inorganic chemistry instructional laboratory course.

Synthetic Methods in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to select the synthetic methods taught in their course from a list of 12 options (see Table 9). The

Table 9. Synthetic Methods ($n = 154$)

	n	%
Using inert atmosphere with Schlenk methods	109	71
Catalysis	80	52
Compressed gases	78	51
Vacuum line	76	49
Using inert atmosphere with drybox/bag	67	44
Electrochemical apparatus	47	31
High temperature furnace/heated tube	44	29
Microwave	28	18
Glassblowing/sealing glass tubes (e.g., synthesis, NMR, elemental analysis)	23	15
Bombs/high pressure reactors for hydrothermal or solvothermal syntheses	16	10
High pressure autoclave	5	3
Flow synthesis	1	<1

largest fraction of respondents (71%) reported teaching inert atmosphere synthetic methods using Schlenk lines. About half of the respondents reported teaching catalysis, compressed gases, vacuum line, and/or drybox/bag techniques in their courses. Approximately a third of the respondents reported teaching electrochemical and/or high temperature synthetic methods. The remaining findings support the highly variable interpretation of the inorganic chemistry instructional laboratory curricula and mirror the variability observed in inorganic chemistry lecture courses.^{2–4}

Purification Methods in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to report the purification methods taught in their course, selecting from a list of eight methods (see Table 10). A key focus (>75% of respondents) was on recrystallization and rotary evaporation. Less common (~33% of respondents) were column/ion exchange chromatography and sublimation.

Table 10. Purification Methods ($n = 169$)

	n	%
Recrystallization	161	95
Rotary evaporation	134	79
Column/ion exchange chromatography	63	37
Sublimation	49	29
Reduced-pressure distillation (e.g., vacuum distillation)	34	20
Resolution of optically active compounds	27	16
Distillation of air-sensitive materials	18	11
Chemical vapor transport	8	5

Characterization Methods in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to select the characterization methods taught in their course from a list of 26 provided (see Table 11).

Table 11. Characterization Methods ($n = 172$)

	n	%
IR	164	95
UV–vis	161	94
NMR: basic techniques (single nucleus)	140	81
Magnetic susceptibility (e.g., Evans method and guoy balance)	115	67
Melting point determination	81	47
NMR: advanced techniques (multinuclear and/or multidimensional)	65	38
TLC	55	32
Voltammetry	53	31
Fluorescence spectroscopy	51	30
Powder X-ray diffraction	45	26
Mass spectrometry	34	20
Thermal analysis (TGA/DSC)	33	19
Single crystal X-ray diffraction	31	18
Conductivity	22	13
Polarimetry	21	12
Electron microscopy (SEM/TEM)	20	12
Optical rotation	19	11
Raman	14	8
Variable temperature NMR	13	8
ESR/EPR	11	6
Optical microscopy	9	5
Atomic force microscopy (AFM)	7	4
Circular dichroism (CD)	5	3
Mössbauer	1	<1
Confocal microscopy	0	0
Magnetic circular dichroism	0	0

Infrared spectroscopy, ultraviolet–visible spectroscopy, and single nucleus nuclear magnetic resonance spectroscopy were taught in over 80% of respondents' courses. Magnetic susceptibility was the fourth most taught characterization method (67%), followed by melting point determination (47%). The remaining characterization methods were taught in less than 40% of respondents' courses.

Professional Skills in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked to choose the professional skills taught in their course from a list of 18 options (Table 12). Written communication is the most taught (97% of respondents) professional skill. Laboratory safety, collaborative/teamwork, literature searching, and hardcopy record keeping is taught by more than 79% of respondents in their courses. The focus on learning how to search the literature corroborates the earlier reported finding that over 50% of experiments used by respondents in their courses involve students researching the theory and background of each experiment (see Table 4). Visualization techniques and oral communication are in a third category of professional skills taught by 60% and 57% of respondents. Remaining professional skills were taught by less than 50% of respondents in their courses.

Table 12. Professional Skills ($n = 173$)

	<i>n</i>	%
Written communication	167	97
Laboratory safety	157	91
Collaborative work (working in teams)	144	83
Literature searching	140	81
Paper/hardcopy record keeping	137	79
Visualization techniques (e.g., using ChemDraw, Jmol, CrystalMaker, etc.)	104	60
Oral communication	98	57
Experimental design	74	43
Computation techniques (e.g., Spartan, WebMO, Gaussian, etc.)	62	36
Ethical conduct of research	47	27
File naming and storage	39	23
Proposal writing	21	12
Electronic record keeping	16	9
Cost-benefit analysis	15	9
Estimating environmental impact	15	9
Glassblowing techniques	10	6
3D printing techniques	4	2
Big data management/training	2	1

Compounds and Materials Synthesized in the Inorganic Chemistry Instructional Laboratory Course

Respondents were given a list of 16 types of compounds and materials and were asked to select those synthesized in their course (see Table 13). Coordination compounds are

Table 13. Compounds and Materials Synthesized ($n = 172$)

	<i>n</i>	%
Coordination compounds	169	98
Organometallic compounds	133	77
Bioinorganic compounds	59	34
Main group compounds	59	34
Nanomaterials	56	33
Oxides	46	27
Polymers	40	23
Hybrid materials (e.g., MOFs)	25	15
Zeolites	19	11
Liquid crystals/sol gels	18	10
Clusters	12	7
Solid solutions	12	7
Supramolecular compounds	11	6
Surface chemistry	5	3
Intermetallics	2	1
Nuclear materials	0	0

synthesized in almost all (98%) respondents' courses. Organometallic compounds are the second most synthesized with 77% of respondents reporting this class of compounds being synthesized in their courses. All remaining compound and material categories were synthesized in a third or less of the respondents' courses. These results suggest a strong molecular focus and less of a solid state focus.

Themes in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked which from a list of nine provided themes are used to frame their course (see Table 14). Overarching themes continue to emerge as an innovative means for connecting courses across the curriculum and

Table 14. Themes ($n = 154$)

	<i>n</i>	%
Connecting structure of compounds to their observable or measurable properties	82	53
Catalysis	34	22
Materials chemistry	28	18
Bioinorganic	14	9
Green chemistry	14	9
Industrial techniques	6	4
Nanoscience	6	4
Environmental chemistry	5	3
"no theme"	52	34

reimagining/transforming the curriculum. Over half of the respondents reported that structure–property relationships were used as a thematic framework. Around 20% of respondents used catalysis or materials chemistry as a thematic framework. Approximately 10% used bioinorganic or green chemistry as a thematic framework. Additionally, approximately one-third of respondents reported that a thematic framework was not used in their course.

Course-Based Undergraduate Research Experiences (CUREs) in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked about their familiarity with course-based undergraduate research experiences^{21–23} (CUREs; see Table 15; "[inorganic laboratory]" was replaced with the

Table 15. Familiarity with CUREs ($n = 161$)

	<i>n</i>	%
I know about this but have never used it in my [inorganic laboratory] course	64	40
I know the name, but not much more	32	20
I currently use it in my [inorganic laboratory] course to some extent	31	19
I have never heard of this before now	28	17
I have tried it in my [inorganic laboratory] course, but no longer use it	6	4

specific course title provided by the respondent). Nearly 1 in 5 respondents stated that they were using CUREs in their inorganic chemistry laboratory courses. Over 60% of respondents reported a level of familiarity with CUREs.

Respondents were then asked about their likelihood of incorporating CUREs into their course (see Table 16). Nearly three-quarters of respondents reported "possibly" to "definitely" likely to incorporate CUREs. For developers and disseminators of CUREs, based on these findings, the inorganic chemistry instructional laboratory course is a target opportunity for implementing CUREs.

Table 16. Likelihood of Incorporating CURE Experiences in the Future ($n = 161$)

	<i>n</i>	%
Definitely	29	18
Very probably	14	9
Probably	10	6
Possibly	65	41
Probably not	36	23
Definitely not	4	3

Assessment in the Inorganic Chemistry Instructional Laboratory Course

Respondents were asked which from a list of 13 provided assessments are used in their course (see Table 17). Of note,

Table 17. Assessment Tools ($n = 158$)

	use		% of course grade			
	n	%	mean	sd	min	max
Traditional laboratory reports (full format or partial)	126	80	51	28	0	100
Laboratory notebooks	124	78	17	17	0	90
Examinations	64	41	37	22	0	80
Oral presentations	56	35	12	9	0	45
Mock journal articles (e.g., using a template from a peer-reviewed journal)	44	28	36	26	0	100
Laboratory practicals (e.g., being observed using specific instruments or performing specific techniques)	38	24	14	12	0	70
Literature reviews	38	24	14	9	0	50
Peer review of other students' work	29	18	8	5	0	25
Poster presentations (posters or oral)	21	13	16	14	3	67
"Cookbook" worksheets (e.g., fill in provided data tables, etc.)	19	12	17	10	5	40
Attitude or affect measures	12	8	11	7	4	26
Creating infographics	4	3	6	3	2	10
Concept inventories	2	1	35	35	10	60

traditional laboratory reports and laboratory notebooks were reported by ~80% of respondents; this suggests that many respondents use classic assessments in their inorganic chemistry instructional laboratory course.

Respondents were then asked to report the percentage of a student's final grade in their course that was determined by each assessment (see Table 17); note: percentage of course grade was asked only if the respondent reported using that assessment type. When used, traditional laboratory reports, for example, make up on average 51% of a student's overall course grade. Similarly, when used, examinations make up on average 37% of a student's overall course grade.

Respondents were also asked who graded laboratory reports for their course ($n = 153$): 88% were graded by an instructor, 10% were graded by a teaching assistant, 1 respondent reported "other faculty members", 1 respondent reported "a staff member", and 1 respondent reported "both them and the teaching assistant". These findings mirror the findings about teaching assistants and other staff that support a respondent's course, with a faculty member primarily being the sole instructional staff for the inorganic chemistry instructional laboratory course.

Finally, respondents were asked to state which of four methods students were expected to use to record experimental notes/data for their course (see Table 18; options were not mutually exclusive). "Other" was an option with one respondent reporting "class wiki"; this is noted in Table 18. For this item, 97% of respondents reported using paper notebooks, with a total of 84% respondents reported exclusively using paper notebooks. There is a growing emphasis on electronic records in the research laboratory contexts with many new products emerging on the market each year. While

Table 18. Methods for Recording Laboratory Experiments ($n = 152$)

	n	%
Paper notebooks	148	97
Handouts/worksheets	12	8
Other digital software solutions (e.g., Google Drive, Evernote, Microsoft OneNote)	11	7
Electronic lab notebook (e.g., LabArchives, PerkinElmer E-Notebook, BIOVIA Notebook, LabGuru)	2	1
Other: ["class wiki"]	1	<1

our data do not provide a means to explore the change in uptake of electronic records in the inorganic chemistry instructional laboratory, it is important to highlight that electronic records (i.e., digital software solutions and electronic lab notebooks combined) are used in approximately 8% of the respondents' courses.

■ IMPLICATIONS FOR INORGANIC CHEMISTRY EDUCATORS

Our analysis of survey responses provides an overview of the inorganic chemistry instructional laboratory curriculum within the United States; inorganic chemistry educators can use these results to evaluate the degree to which their own laboratory instruction aligns with that of the larger community. Given that the inorganic chemistry curriculum^{2–6,15} is less defined compared to general chemistry and organic chemistry, this overview provides a useful guide for designing new laboratory courses. For instance, instructors could compare synthetic methods included in their course to those in Table 9 and make choices about including or excluding particular methods. The results in Table 13 indicate a current emphasis on molecular chemistry, and instructors may wish to develop more solid state, material, or polymer focused experiments to reflect the growing importance of those areas. Educators could also use this overview when revising their own courses to identify alternate instructional approaches commonly employed in inorganic chemistry laboratory curricula. Importantly, however, the prevalence of a given experimental method, assessment type, or other component of laboratory instruction is not necessarily associated with evidence-based instruction;²⁶ though, work should be done to establish such evidentiary support. Inorganic chemistry educators, therefore, should make descriptive rather than prescriptive comparisons as they consider relevant findings from chemistry education research to transform their course or degree program curriculum; in other words, the results herein should not be considered as what should be done, but informative as to what is currently done.

The inorganic chemistry laboratory curriculum reported herein suggests a unique opportunity for revising and transforming related courses. Survey responses provide inorganic chemistry educators with several promising avenues for reform. Inorganic chemistry laboratory instructors reported a small average class size (mean = 12, SD = 9), though approximately 80% of respondents reported using very traditional assessments of learning in the form of laboratory reports and notebooks. Respondents also stated that just 15% of laboratory experiments met the criterion for the highest level of inquiry-based experiment in which students must choose the problem or question to be investigated. Further, approximately one-third of respondents reported that their course did not

incorporate a thematic framework. Small average class sizes, combined with flexibility in inorganic chemistry content coverage, may facilitate (1) the use of in-depth assessments that evaluate learning in situated, disciplinary contexts and (2) the adoption of instructional laboratory experiments that incorporate high levels of inquiry and student autonomy. Lastly, flexibility in content coverage may allow instructors to readily incorporate thematic frameworks. Organizing courses around a central theme (e.g., materials chemistry or green chemistry) would support meaningful learning by having students make relevant connections across experiments as they construct knowledge within the given theme.

■ IMPLICATIONS FOR CURRICULUM DESIGN AND POLICY

The role of inorganic chemistry in the field of chemistry has never been more important; materials, nanoscience, catalysis, green chemistry, environmental chemistry, among others, require an understanding of inorganic chemistry.^{2–4} Despite its central role in chemistry, inorganic chemistry has had a variable presence in the undergraduate curriculum.^{2–6,15}

The ACS Committee on Professional Training's Guidelines and Evaluation Procedures for Bachelor's Degree Programs require that "student laboratory experiences must include only four of the five subdisciplines."¹⁸ It is important for students to have hands-on experiences synthesizing different classes of materials, preparing samples and reagents, conducting air-free manipulations, purifying materials, preparing samples for measurement using instrumentation, selecting reactionware, handling chemicals safely, and appropriately disposing of waste.²⁷ While these skills can be addressed in other parts of the curriculum, we believe that the inorganic laboratory provides an ideal environment to use these skills with diverse materials and instrumentation and feel that it is an essential element of chemistry laboratory education.

The absence of inorganic chemistry specific instructional laboratory coursework in some programs is concerning. While we believe that integrated laboratory experiences have the potential to provide excellent instruction in inorganic chemistry, we, the authors, remind policymakers that inorganic chemistry plays an important role in the broader chemical sciences, and students should receive sufficient instruction in inorganic laboratory techniques, synthesis, and characterization. Additionally, students should work with a broad range of materials across the undergraduate curriculum.

Resources, such as this *Journal* and VIPEr,¹⁶ continue to play an important role in designing and disseminating curricular materials that can easily be adapted to the various laboratory (and lecture) inorganic chemistry courses. However, the findings of our study are an opportunity for curriculum designers to provide guidance as to how parts of a laboratory experiment can be augmented or removed to suit the available resources and equipment in each instructional laboratory context. Course-based undergraduate research experiences provide another avenue for ensuring a lasting focus on inorganic chemistry instructional laboratory courses in the postsecondary chemistry curriculum.^{21–23} Such courses complement the inorganic chemistry research focus (i.e., use of primary literature in inorganic chemistry instruction^{1,2,25}) that was reported by our survey participants.

■ IMPLICATIONS FOR EDUCATIONAL RESEARCHERS

Our analysis provides insight into synthetic, purification, and characterization methods commonly incorporated into inorganic chemistry instructional laboratory courses. However, the degree to which these methods align with methods routinely used by practicing inorganic chemists is uncertain. Similarly, alignment between classes of compounds and materials most often synthesized in instructional inorganic laboratory courses and those typically synthesized by practicing inorganic chemists is uncertain. Methods and synthetic products may be incorporated into courses for a range of factors beyond disciplinary relevance, including accessibility, ease of use, and cost efficiency. Conversely, methods and synthetic products particularly relevant within the discipline may be omitted from instructional courses given their inaccessibility, complexity, or cost. Additionally, alignment between assessment tools used to evaluate learning in the laboratory should be evaluated with learning emphasized in instruction. For example, professional skills are ranked high in importance, whereas the commonly reported assessment tools focus heavily on professional skills such as oral and written communication. Future research should focus on determining this degree of alignment, including underlying causes of misalignment, to support the design of an inorganic chemistry laboratory curriculum that adequately prepares students for participation in the contemporary chemical enterprise.

Additionally, much has been investigated about the student experience in general chemistry and organic chemistry instructional laboratory courses.^{8,9,12} There is a need for further exploration of the learning goals and affective experiences of students in upper-level instructional laboratory courses, especially as these courses are touted as when students are solidifying decisions about careers and further studies.

■ CONCLUSION

A national survey of inorganic chemists ($n = 174$) was conducted that captured the current state of the postsecondary inorganic chemistry instructional laboratory curriculum. A parallel trend in course format, content, focus, assessment, etc. was observed for the inorganic chemistry instructional laboratory course as has been previously observed for the inorganic chemistry lecture course. The results of this work suggest an opportunity for transformation of this instructional laboratory context by integrating more evidence-based and inquiry-based instructional laboratory experiences. Finally, the results of this work provide a descriptive account that inorganic chemistry educators can use to design and transform the instructional laboratory curriculum.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemeduc.2c00092>.

Survey instrument (PDF, DOCX)

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J.R.R., J.M.P., S.R.S., J.L.S., B.A.R., A.K.B., and S.L. conceived the project. J.R.R., J.M.P., S.R.S., J.L.S., B.A.R., A.K.B., S.L., and C.N. developed the survey instrument. J.R.R. and J.M.P. collected data and conducted data analysis. J.R.R., J.M.P., M.C.C., S.R.S., J.L.S., B.A.R., A.K.B., S.L., and C.P. discussed data analysis, assisted in interpreting results, and articulated implications of the results. J.R.R., J.M.P., and M.C.C. authored the paper. J.R.R., J.M.P., M.C.C., S.R.S., J.L.S., B.A.R., A.K.B., S.L., and C.N. reviewed and edited the paper. J.R.R. and J.M.P. contributed equally to the project.

Notes

The authors declare no competing financial interest.

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