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Learning Goals and Priorities Identified by an Examination of Chemistry Graduate Handbooks

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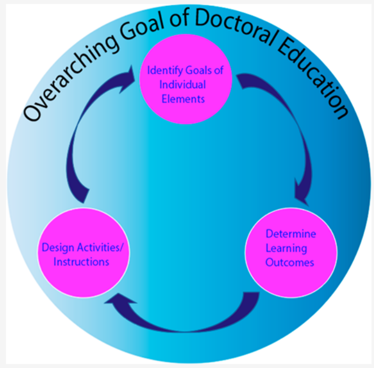
ABSTRACT: The commonly accepted goal of doctoral education is to train students to be independent researchers and scientists. The backward design framework was used to model how graduate handbooks should be developed; by setting measurable outcomes and working backward to design programmatic elements that will meet those desired goals. Under the backward design framework, each of the programmatic elements of doctoral programs is based on learning goals designed to help to progress students to accomplish this overarching goal. Because the graduate student handbook represents the primary documentation of programmatic elements, it is possibly the only place where learning goals are explicitly written out. In this qualitative study, publicly available graduate handbooks from 60 chemistry departments were investigated for the learning goals of the programmatic elements to know how these contribute to the overarching goal of graduate education and compared to a literature-based model of the goals of each major programmatic element. Through document and thematic analysis, we found that most handbooks did not explicitly state the learning goals of the programmatic elements, indicating that backward design was not likely implemented fully during the crafting of these documents. Considering the prior success of backward design, this study implies that graduate handbooks written with an explicit alignment with backward design could better prepare students for the workforce and more broadly meet the desired goals of doctorate-level chemistry education.



KEYWORDS: *Chemical Education Research, Doctoral Education/Research, Graduate Student Handbooks, Backward Design Framework, Programmatic Elements*

INTRODUCTION

To continually solve the world's crucial problems while maximizing advancement, there is a need of people with advanced knowledge and skills.[1−3] According to the American Chemical Society (ACS), the main goal (ultimate outcome[4]) of doctoral education is to produce students capable of solving problems in society by becoming scientists proficient in conducting independent research.[5,6] Each year, about 2,900 students receive their doctoral degrees from the 196 chemistry programs in the U.S.[7,8] Over several decades, the structure of doctoral education in chemistry fundamentally consists of the same programmatic elements: **research**, **coursework**, **seminar**, **candidacy exam**, **teaching assistantship**, etc.[8−10] However, the effectiveness of doctoral education in chemistry has been questioned by several researchers.[10−13] It is believed that to be employed, one is expected to have certain knowledge and skills.[14,15] Yet, recent studies revealed that most chemistry doctoral graduates significantly lack skillsets their employers' value.[16,17] To overcome this issue, the government and universities must reconsider the primary intended goal(s) of a Ph.D. program.

Most prior studies focus on doctoral education as a whole as opposed to examining the goals of the individual programmatic elements that comprise doctoral education and how they fit together to achieve the overall goals.[6,11,18] Backward design is a method of designing curriculum or learning activities with the desired learning goals in mind and can be applied to graduate programs as a whole or each individual programmatic element (Figure 1).[19] This process is widely used in education and shown to enhance student learning.[20,21] The process necessitates defining goals, outcomes that will demonstrate whether those goals were met, and activities designed to prepare students in relation to those goals.[22] Learning goals are what students are expected to know, understand, and be able to do. In contrast, learning outcomes are specific performances or behaviors (acceptable evidence) that will indicate whether the stated goals are achieved.[22,23] Learning outcomes are measurable and may include detailed criteria that describe the different levels of acceptable evidence.[23] Finally, learning activities are the experiences and instruction that will enable a student to achieve the learning goals.[22] The alignment of

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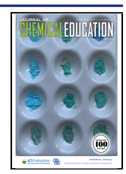

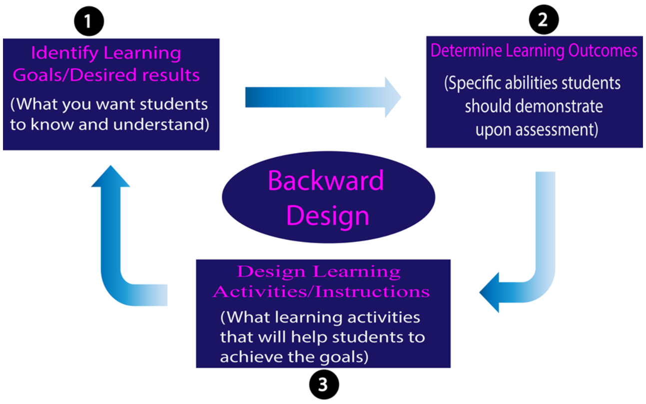

Figure 1. Backward design.[22]

learning goals, outcomes, and activities is at the core of backward design and is the primary factor in determining the degree to which a program is or is not successful.[24] For instance, a previous study utilized backward design in redesigning a general chemistry laboratory curriculum by having 17 learning goals in mind and working toward achieving them.[25] After the introduction of five laboratories to the redesigned curriculum, there was a 33% increase in meeting the learning goals in comparison to the original curriculum. This shows the effectiveness of backward design in helping students to achieve learning goals.

Applied to chemistry graduate education, it may be beneficial to design graduate programs with explicit alignment among the stated goals, objectives, and activities of the graduate program. To the best of our knowledge, there is no other place where the learning goals of the individual programmatic elements would be as explicitly documented outside of the handbooks. Consequently, graduate student handbooks are likely the most pertinent and sometimes the only document whereby the designers of the program will have detailed relevant learning goals. Learning goals, whether explicitly stated or not, are key in the training of graduate students, as they represent the major takeaways that would transform a novice student to become a professional. These goals theoretically describe how the individual programmatic elements of chemistry doctoral education contribute to the overall goal(s) of doctoral education. However, the literature surrounding graduate handbooks is largely silent on their purpose. A brief review of reports from national agencies that delineate key elements of doctoral education and reform[6,13,26−33] found that only one[34] even mentioned handbooks. Handbooks appear to contain policies governing students' actions within the doctoral program,[35−38] suggesting that a key purpose of handbooks is to communicate rules and guidelines. However, considering the handbooks we reviewed as part of this study, we also note that this is not exclusively their purpose. For example, several handbooks[39−42] clearly go beyond policy and introduce learning goals for the programmatic elements students will face. This suggests that at least some departments see the role of handbooks as a syllabus of sorts for doctoral programs in that they convey both the policy and the purpose of educational activities. Previous researchers have raised issues in regard to improving the information provided in graduate student handbooks,[35,36,37,43] but no study has focused on the graduate student handbook's role as a "syllabus" for doctoral education in chemistry.

Our study assumes that incorporating backward design in graduate handbooks could better prepare students for the workforce and more broadly meet the desired goals of doctorate-level chemistry education. As a result of this assumption, we must first assess the extent to which graduate handbooks detail the learning goals of the key elements in which graduate students will participate. To this end, our study seeks to answer two main research questions through the lens of backward

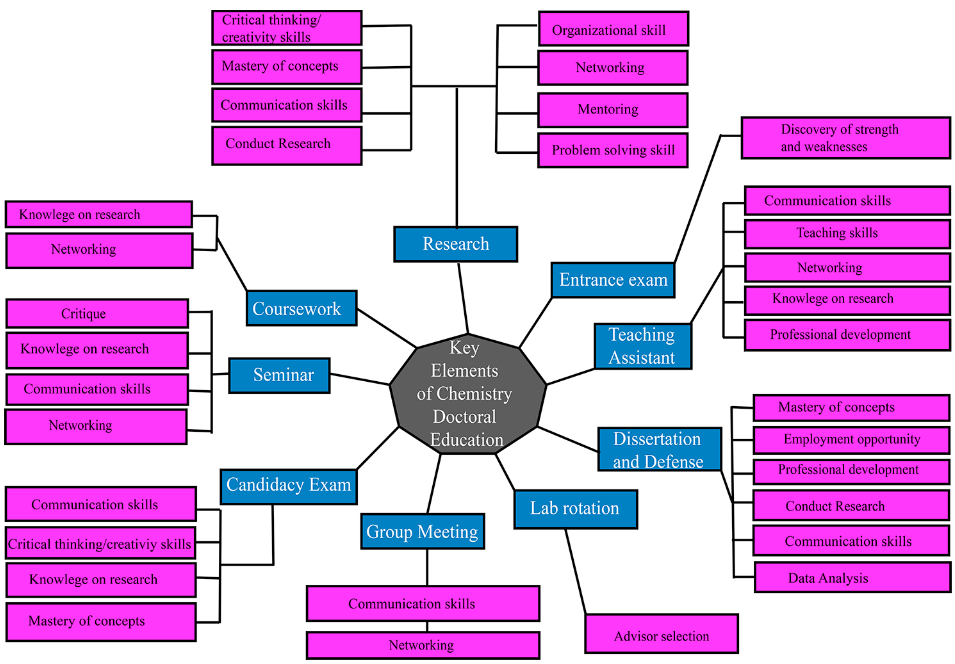

Figure 2. Summary of key programmatic elements in doctoral education (identified in the literature) and how the literature describes their intended learning goals. The blue colors represent the programmatic elements of doctoral education, and the purple colors represent the learning goals obtained from the literature. See Supporting Information for more details.

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design: i. What are the learning goals of the individual programmatic elements found in the chemistry graduate student handbooks? ii. How do the individual learning goals of these programmatic elements contribute to the overall goal of chemistry doctoral education?

■ METHODS

Theoretical Framework

To effectively assess learning goals in chemistry graduate student handbooks, our study examined the handbooks through the lens of backward design (Figure 1) meaning we expect that the learning goals of programmatic elements should be explicitly delineated.[22] Backward design shifts the paradigm from a "content-centered program to a learning-centered program/outcome-centered program design".[4,44] It increases the chances to obtain a high level of student engagement since this process steers those who design the programmatic elements toward implementing student-active teaching and learning strategies. To answer the first research question, our study focused on mining handbooks for the learning goals of the individual programmatic elements of chemistry doctoral education. A quick review of the initial handbooks revealed the presence of learning goals of some programmatic elements, emphasizing that some chemistry departments explicitly state learning goals of programmatic elements in their handbooks.

Additionally, we need a model that describes the purposes of common elements in doctoral programs. We examined extant literature (details can be found in Supporting Information, Appendix A) to identify learning goals attributed to the programmatic elements in doctoral education in chemistry *from the research literature*. As an overview, examples of learning goals we identified for **research** from the literature were to obtain hands-on experience in the primary research methods of a discipline which was given a code *conduct research*, ability to solve problems coded as *problem-solving skills*, to articulate and address critical issues in a field of study coded as *communication skills*, etc.[45−50] In addition, examples of learning goals identified for **candidacy exams** were the ability to be creative which was coded as *critical thinking/creativity skills*, the ability to communicate research work to others effectively coded as *communication skills*, etc.[11,18,45,46] while examples of learning goals identified for **seminars** were the ability to critique presentation of others which was coded as *critique*, and to gain the breadth of knowledge in a field coded as *knowledge on research*, among others.[11,51] The learning goals we identified in the literature for the programmatic elements of doctoral education in chemistry are summarized in Figure 2 (the details of the learning goals identified for the programmatic elements can be found in the Supporting Information Appendix A). In this literature, programmatic elements were tied to relatively opaque learning goals such as "critique presentation of others" for **seminars**, "be creative" for **candidacy exams**, or "apply advanced knowledge and skills" for **coursework**. These learning goals and respective doctoral education in chemistry programmatic elements can be examined in the summary depicted in Figure 2. A common framework to evaluate learning goals are the SMART goal framework that suggests learning goals should be <u>s</u>trategic-(<u>s</u>pecific), <u>m</u>easurable, <u>a</u>ttainable or <u>a</u>ctionable, <u>r</u>elevant (<u>r</u>esult-based), and <u>t</u>ime-bound,[52] threatening their utility. A quick review of Figure 2 reveals many vague and arguably non-SMART (*e.g.* not specific, not measurable, *etc.*) learning goals, drastically limiting the theoretical goals of each doctoral education in chemistry element.

In addition to a lack of precise learning goals leading to a lower chance of achieving desired goals, students who identify as people excluded on the basis of ethnicity and race (PEER) and first-generation students are more likely to face attrition if programs are not targeted.[53,54] Due to systemic factors, most PEER and first-generation students are less exposed to vital information about education in comparison to other students who are not in this demographic and will more likely need clear expectations of doctoral programs.[55−57] Hence, a guide with clear learning goals would likely disproportionately benefit this group.[11,35,36,58]

Data Collection

Graduate Handbooks (54) and information from six Web sites (did not have a formal handbook but had similar information posted online) were investigated from 60 chemistry departments in the US. Also, due to the fact that **teaching assistantships** are a programmatic element of chemistry doctoral education, we examined graduate teaching assistant handbooks specific for the chemistry departments in this study as well. However, only one chemistry department had a publicly available teaching assistant handbook which had a similar learning goal as the graduate handbook for the **teaching assistant** element. The institutional sample is based on the "top 20", "middle 20", and "bottom 20" from the best chemistry graduate programs ranked by US News & World Report.[59] While we express healthy skepticism in this perspective-based ranking system,[60] we used the ranks in an attempt to get a broad distribution of chemistry graduate programs that likely represent "elite", "average", and "lesser-known" programs.

Data Analysis

Document analysis approach (qualitative) was used in this study with the aim of investigating learning goals in graduate student handbooks. Document analysis involves the process of detailed reading, skimming, examining the content, and interpretation of documents.[61,62] Thematic analysis was used to identify the detailed information behind codes and understand how key factors of programmatic elements influence chemistry doctoral education.[14,62] In this study, we adopted the use of inductive coding in the following manner: The initial step of the coding involved collating the individual programmatic elements mentioned in the "handbooks". Afterward, the learning goals associated with each programmatic element were identified from the graduate student handbooks using words like "purpose", "scientific aims", "learning outcome", "benefits", developed to", "intended to", "designed to", "objective" "meant to", "aim", "goal", "focus", etc. and the data inductively provided with a code. The list of codes was compared and sorted into categories of learning goals (sorted according to codes that were similar in nature and related to the research questions) based on backward design. For example, the codes, "*carryout research*", "*scientific and practical significance of research*", "*latest research update*", "*new research*", and "*research techniques*" were combined into the learning goal category "*conduct research*" (see details in Table S1). These codes were similar, as they involved conducting research and giving updates on the research conducted. Hence, they were summed into a category called *conduct research*. The same analogy was applied to other similar codes. The codes were developed manually in Microsoft Excel.

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The definitions of the codes can be found in Table S1. See Table S2 for examples of the various learning goals for the codes.

Inter-rater Reliability

After the initial codebook was developed by the author BD with input from JH, three external coders were used to establish the credibility of the *data analysis*. The external coders each have a background in chemistry education: a postdoctoral researcher and two doctoral students. Each coder independently identified the learning goals of the individual elements of chemistry doctoral education directly from five graduate student handbooks. Afterward, author BD compiled the external coder's findings along with her own, and each coder was allowed to give feedback on the compiled data wherever there was a disagreement between the coders. Following this, inter-rater reliability was calculated between all four coders (author BD and three external coders). *The calculated inter-rater reliability is shown in Table 1*, using three inter-rater reliability (IRR) metrics. Percent agreement is a widely used measure to calculate IRR, however, its calculation can vary, often resulting in more liberal (higher) estimates than is warranted.[63] For this work, the average agreement, Fleiss' kappa,[14,64] and Krippendorff's alpha[65] all demonstrated an acceptable IRR.[14,66] This indicates that there is a high degree of agreement among the four coders in terms of the learning goals identified in the graduate student handbooks.

Table 1. Inter-rater Reliability Results

Inter-rater Reliability Method	Results
Fleiss kappa	0.970
Krippendorff's alpha	0.964
Percent Agreement	0.945

RESULTS AND DISCUSSION

Learning Goals of Individual Programmatic Elements

A total of 14 programmatic elements were identified throughout the handbooks (Table 2). These were consistent with those programmatic elements reported in the literature.[8,18,34,67] Of the 14 programmatic elements, we did not examine learning goals for either advisors or advisory committees because these are not accurately perceived as programmatic elements of a program that have specific learning goals (*i.e.*, the purpose of having an advisor is ...) as opposed to serving various roles that are likely not effectively captured by a backward design framework.

Table 2. Abbreviations Used for Programmatic Elements in Order As They Appear in Figure 3

Programmatic Element	Abbreviation
Exit Interview	EI
Entrance Exams	EE
Publication Requirement	PB
Group Meeting	GM
Annual Meeting	AM
Lab Rotations	LR
Seminars/Colloquia	SM
Research (leading to dissertation)	RS
Teaching Assistantship	TA
Courses of Instruction (Coursework)	CW
Dissertation and Defense	DD
Candidacy Exams (prelims, comps, cumes, original research proposal, etc.)	CE

With some exceptions, we identified relatively few chemistry departments that stated learning goals explicitly for many programmatic elements (Figure 3, broken down by chemistry departments in Figure S1). After thematic analysis of the collective learning goals mined from the handbooks of all the chemistry departments, twenty-three unique learning goals were identified (see Figure S2). The specific learning goals of the respective programmatic elements discovered in the handbooks are discussed in light of the summary of the learning goals of the programmatic elements found in the literature (Figure 2) and guided by the theoretical framework. The following results are discussed by individual programmatic elements in the order in which they appear in Figure 3.

Candidacy Exam

Candidacy exams refer to preliminary, comprehensive, cumulative, general, candidacy, and proposition exams or original research proposal, as they all serve the purpose of transitioning a graduate student into becoming a Ph.D. candidate. This is in alignment with a previous study that reported different types of examinations conducted to serve the purpose of transitioning graduate students to candidacy.[68] From the results, the **candidacy exam** was the programmatic element for which the majority of the chemistry departments (78.3%) stated at least one learning goal. Sixteen distinctive learning goals were identified in the handbooks. The most common learning goals found for the **candidacy exam** were *knowledge on research*, *communication skills*, *planning/organizational skills*, and *critical thinking/creativity skills*. The other learning goals can be found in Figure S2. However, most of the learning goals are geared toward *assessing* the acquired skills to ascertain whether students will be able to successfully complete the program as opposed to *providing* students with those goals upon completing the **candidacy exam**.[34] This aligns with a previous finding where **candidacy exams** were used to make summative decisions in regard to a candidate's ability to continue in the graduate program.[45] In terms of backward design, this programmatic element is more appropriately thought of as an indicator of an outcome (summative assessment, primarily for evaluative purposes) as opposed to the outcome itself (formative assessment, primarily for growth/development), and the language in the handbooks supports this notion.

Dissertation and Defense

All the chemistry departments mentioned **dissertation and defense** in their handbooks, and 46.6% of them delineated learning goals. Notably, one chemistry department clearly stated that **defense** was not a requirement. Eight learning goals were discovered for this programmatic element, with *conducting research*, *communication skills*, and *knowledge on research* being the primary learning goals. The **dissertation** is known as the ultimate educational product of its author[69] and the oral **dissertation defense** is to test a candidate's "general" knowledge.[68,70] In the handbooks, *employment opportunity* (preparing for a career) and *professional development* (be professionals in a field) were not found as learning goals for **dissertation and defense** despite the apparent implications of formally obtaining the Ph.D. (through defending) has on one's career. It could be that this is simply an assumed learning goal not worth explicitly listing, but still is not aligned with

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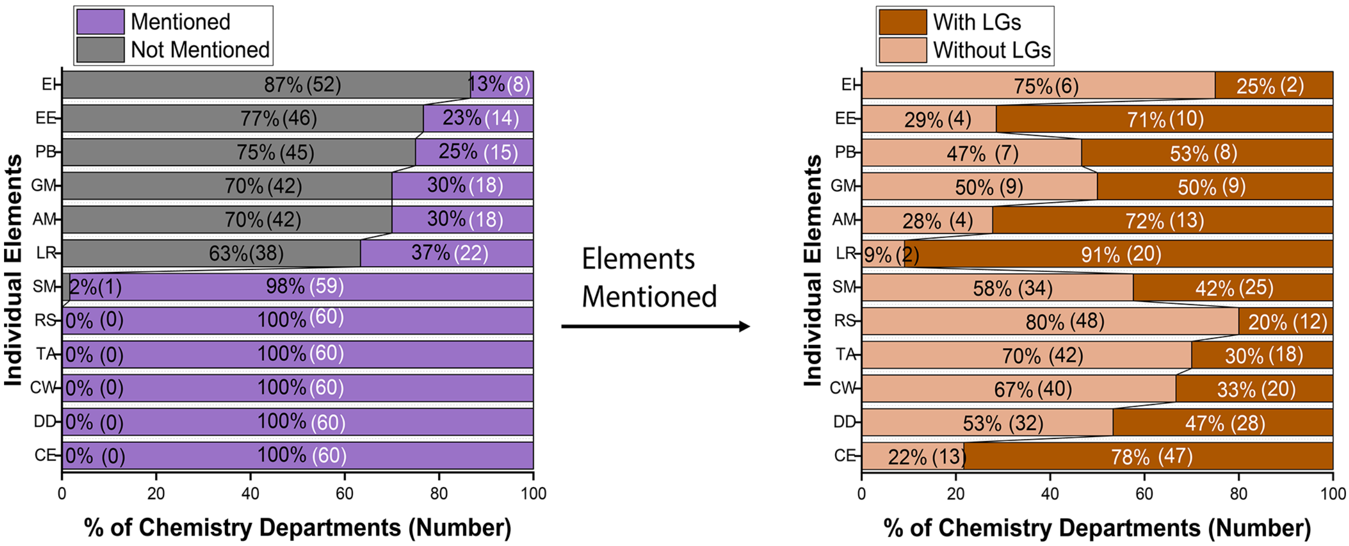

Figure 3. Left graph shows programmatic elements that were identified/not identified in analysis of handbooks; of those programmatic elements that were identified, the right graph shows the counts/percentage of programmatic elements where learning goals were/were not identified. An example interpretation of the top row: 8 (13%) of handbooks have exit interviews (EI) as a programmatic element (left graph); of those 8 handbooks, 2 (25%) explicitly listed learning goals for the exit interviews, while 6 (75%) did not (right graph).

backward design. It is reasonable that *conducting research* is the major learning goal for **dissertation and defense** as the ability to conduct research is required for a dissertation.[45] *Communication skills* in both written and oral form are also very important in writing/defending a dissertation. If data or results of a study conducted are not communicated well, then the study becomes irrelevant. Without knowledge on the research to be conducted, there is no way one could succeed, hence the learning goal, *knowledge on research* is the next major after *communication skills*. Even though these three were found to be the main learning goals, additional learning goals in the handbooks are found to be *teaching skills*, *problem-solving skills*, and *data analysis*.

Coursework

Coursework is a staple element of graduate programs, yet only a third of the handbooks listed learning goals for this programmatic element (seven unique learning goals identified). *Communication skills*, *data analysis*, and *knowledge on research* were the major learning goals in the handbooks obtained for **coursework**. *Knowledge of research* uncovered in the handbooks is the main learning goal of **coursework** which is consistent with Figure 2. This is because broad training in the fundamentals of chemistry is essential for novice graduate students to survive and thrive in the program.[45] However, like with **seminars**, it is disconcerting that such an accepted programmatic element is so frequently mandated without explicit justification necessitated by backward design. *Networking* was discovered in Figure 2 but none of the handbooks mentioned this as a goal for the programmatic element. This may be interpreted as *networking* not being considered a goal for **coursework** or not explicitly written in the handbooks of the chemistry departments investigated.

Teaching Assistant

About 30% of the chemistry departments stated explicit learning goals of TA, which unsurprisingly included *teaching* and *communication skills* as the most common. All learning goals related to **teaching assistant** in Figure 2 were found in the handbooks for the programmatic element, with the exception of *networking*. The most prominent learning goal of TA found in the handbooks was *teaching skills*. This may be more related to the fact that the majority of duties assigned to teaching assistants are teaching.[71] To be able to teach, it is necessary to be able to communicate with one's students, hence unveiling *communication skills* as the next important learning goal. Most employers see teaching as an important skill that chemistry programs need to incorporate in the training of their graduate students.[72] Also, the relatively few learning goals identified for TA positions is primarily to relieve students of financial burden as opposed to having significant pedagogical value, an argument made previously.[73] This could also be the reason why most stakeholder groups in graduate education agreed that teaching assistantships should be used more strategically for the professional development of students.[74]

Research

From our results, 20% of the chemistry departments had learning goals for **research** leading to ten distinct learning goals. The main learning goal for **research** was *conduct research*. As **research** is the central and most important programmatic element of a doctoral program,[75,76] it is interesting to note that only a small number of departments chose to list explicit learning goals. It could be that this programmatic element is viewed as the definition of a graduate program such that the overarching goals of the program are equivalent to those of this individual PE. Alternatively, it could mean that departments have not given adequate thought to what the goal(s) of dissertation **research** should be. A previous ACS report raised concern that due to the fact that doctoral education is primarily focused on research, most graduates are not trained effectively in other important workforce skills such as communication, and the ability to work in a team among others which are critical for US workforce.[2] From this study, *conducting research* is the major learning goal highlighted in the handbooks, confirming the finding of the previous report. However, other minor learning goals such as *communication skills*, *networking*, *developing good ethics*, *data analysis*, and

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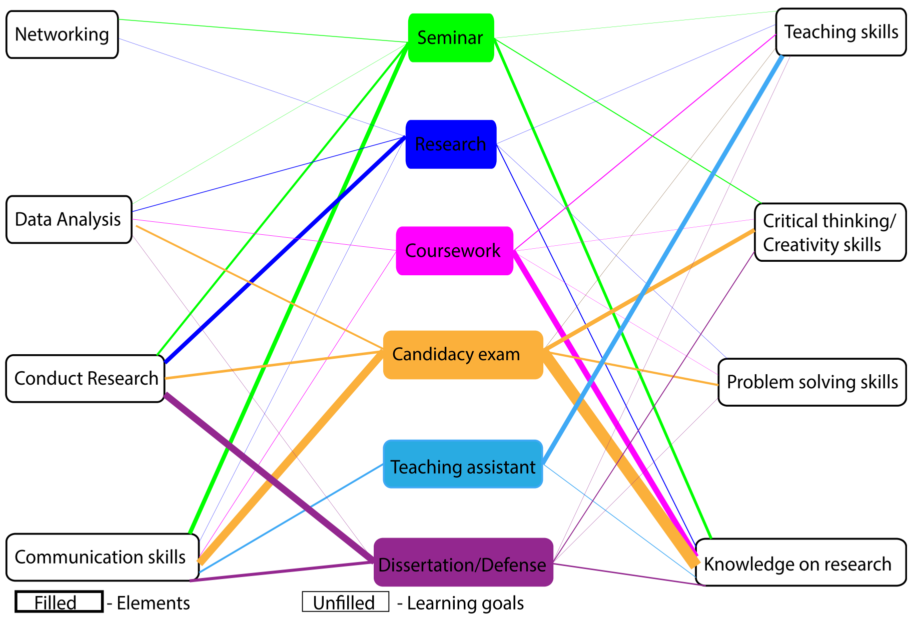

Figure 4. Programmatic elements mentioned by all the chemistry department handbooks (colored) and their links to the summarized learning goals identified in literature (white filled) where the thickness of each line represents the relative number of graduate handbooks that listed that learning goal (thickest line represents $N = 51$; thinnest represents $N = 1$). Note: Additional learning goals discovered from the handbooks can be found in Figure S2.

teaching skills were discovered as well, just not as often. The *communication skills* and *networking* aligns with two of the six professional development skills students need as highlighted in a previous study.[77] These minor learning goals discovered in the handbooks address some of the vital skills that students normally lack according to the ACS report. If these are considered as major learning goals of **research**, it would be crucial for chemistry departments to state those in the handbooks so that it does not seem as if *conducting research* is purely for the purpose of having someone to conduct research (*i.e.*, a job where the service provided is of more importance than the professional growth of the student). Six of the learning goals found in the handbooks are similar to those found in Figure 2. However, *critical thinking/creativity skills* and *mentoring* were not found in the handbooks in comparison to those in Figure 2. This could mean that even though both were identified as learning goals of **research** in Figure 2 (the literature), designers of the handbooks do not consider them as learning goals of this programmatic element. It could also be that while they are considered as learning goals, they were not featured in the handbooks as indicated elsewhere that the goals of chemistry doctoral programs are not explicitly set forth.[78]

Seminars

Seminars refers to the requirement to attend or present at **seminars/colloquia** at the departmental or divisional levels. Nearly all chemistry departments require **seminar** attendance, and approximately 42% stated at least one learning goal for doing so. Fourteen different learning goals were collectively discovered in the handbooks for **seminars**. *Communication skills*, *knowledge on research*, and *conduct research* were discovered as the main learning goals of **seminars**. **Seminar** demonstrated the tightest alignment from Figure 2 to what was represented in the handbooks. To be able to convey one's research findings or ideas to others, it is very important to have good *communication skills*; hence, that was the main learning goal for **seminars** in the handbooks. Obtaining chemistry knowledge is fundamentally ingrained as valuable in graduate programs, likely explaining why "*knowledge on research*" was the next most important learning goal found in the collective handbooks. Even though sometimes students are expected to present the findings of others during **seminars** (literature survey), communicating findings from one's own research is often required, explaining why "*conduct research*" was the next most important learning goal. It is notable, however, that over half of the chemistry departments require **seminars** without explicitly providing learning goals for doing so, misaligning their handbooks with a backward design.

Lab Rotations

Lab rotation is a period where students interact with advisors, postdocs, and other graduate students in several laboratories for defined periods of time and decide on which laboratories to join.[79,80] While only a third of the programs studied implement them, LR received the greatest proportion of chemistry departments that state learning goals (Figure 3). Six unique learning goals were identified for **lab rotations**, the most common of which was for a student to select a formal research advisor followed by conducting research (Figure S2), consistent with previous reports showing increases in **lab rotations**.[7] Choosing an advisor is not a knowledge or skill that students gain but rather something that (theoretically) will lead to development of skills and knowledge. Therefore, the most common learning goal associated with **lab rotations** hinges on the success of the advisor to promote beneficial goals for the student. Other programs delineated more specific, direct learning goals for **lab rotations** (e.g., *conduct research*, *problem-solving skills*, *networking*, etc.) that appear to be more in alignment with backward design, but these represent the minority of chemistry departments.

Annual Meeting

Ten learning goals were discovered across the 19 chemistry departments that reported **annual meetings** in their handbooks with *research progress* and *communication skills* as the primary learning goals. The relatively minor number of programs mentioning **annual meetings** may signal the limited value of these as a primary PE. However, the major learning goals identified (*research progress* and *communication skills*) are likely to play huge roles in the development of independent scientists. Also, *mentoring* (learning goal) was discovered to be associated with this programmatic element because it mostly involves research advisors and advisory committee members (mostly known to be a guide and additional resource to students).[37,81]

Group Meetings

Similar to **publication** requirements, half of the 18 handbooks that mentioned **group meetings** stated their intended learning goals, but like **lab rotations**, *advisor selection* was the main purpose of **group meetings**. While being described in the handbooks as primarily for the purpose of *advisor selection*, Figure 2 describes the major learning goal of **group meeting** as *communication skills*. This may mean that either this programmatic element is not necessary for graduate students' growth (as 70% of the chemistry departments did not mention it) or the handbooks were not designed to elaborate on this particular PE. However, *networking* in Figure 2 is in alignment with the handbooks.

Publication

Approximately half of the 15 handbooks that mentioned **publication** as a requirement had learning goals tied to this requirement. Because of the intuitive connection between **publications** and **research**, it is unsurprising that the most common learning goal was *conducting research*. While 75% of chemistry departments did not state **publications** as a requirement, it is possible that individual advisors formally require publications. Given the many pitfalls in the peer review and **publication** process,[82,83] learning goals tied to **publication** requirements are crucially important to rationalize adequately.

Entrance Exam

Entrance exams refer to registration, matriculation, basic, background, and placement exams as they serve similar purposes. Of the 60 institutions, 14 mentioned **entrance exam** and 71% of them had learning goals, supporting the trend noted by the ACS that these are declining in popularity.[7] Four unique learning goals were identified for the **entrance exam** with *knowledge on research* and *discovery of strength and weakness* being the major ones. This is consistent with a previous study which stated **that entrance exams** are to judge the breadth and soundness of the undergraduate training of students.[7]

Alignment to the Summary of Learning Goals of the Programmatic Elements (Figure 2)

Figure 4 compares the learning goals of the programmatic elements found in the literature (Figure 2) with the results presented from analysis of graduate handbooks. This visual represents the overlap between what is discussed in the literature versus graduate handbooks, assuming that the learning goals of doctoral education in chemistry are fully represented in graduate handbooks (see Limitations) and serves as the answer to the second research question. The first implication is the heavy emphasis that doctoral education in chemistry appears to hold *knowledge on research*. This is evidenced by the fact that it contains the most and thickest lines. This supports prior critiques that doctoral education in chemistry is first and foremost a program that trains students for knowledge mastery with transferable skills as a secondary goal.[6,30,84] However, these skills are not entirely absent, just tied to programmatic elements other than the primary programmatic element of **research**. Noteworthily, the thickest line (54 learning goals) does not mean 54 handbooks stated *knowledge on research* as a learning goal. Some handbooks mentioned more than one learning goal for that specific programmatic element, which were all categorized as *knowledge on research* learning goal.

General Comments on the Learning Goals found in the Handbooks

Generally, looking through the lens of backward design, most of the chemistry departments investigated in this study did not explicitly state the learning goals of the individual programmatic elements, which is consistent with a previous commentary.[78] However, important learning goals were also identified (as discussed above) from the relatively few that stated the learning goals in their handbooks, which is essential for graduate students to have. This implies that at least some departments find it beneficial and appropriate to include learning goals and outcomes in their graduate handbooks, likely as a way to inform students of what they should expect to get out of the program. We also saw some anecdotal evidence of this idea with the statement of purpose for the handbooks. An example of a quote from one of the handbooks was "*these requirements are established to enable students to progress through their program in a productive and timely manner*". Statements like this imply that the handbook may help to promote student learning in addition to solely providing policies and rules. Additionally, some of the handbooks clearly state that they are open to adding other important information that may be beneficial to their students. "*Since we intend to revise this handbook periodically, please let the graduate program administrator know if there are any additional topics that should be included*" is a quote directly from a handbook that emphasizes this. For chemistry departments to contribute their mission (training students to gain the required knowledge and skills) most effectively, it is recommended that the designers of the program incorporate the learning goals of the individual programmatic elements into the handbooks. Explicitly stating the learning goals of the individual programmatic elements of doctoral education could likely help students value the programmatic elements more, have easy access to them, and build self-consciousness toward achieving them. With clearly articulated learning goals, it may be easy to identify students' weaknesses and remediate them.[74] This may alleviate some of the burden universities pay off in their role of ensuring students obtain the appropriate required knowledge and skill sets that they would mostly need. Collectively, all these learning goals discovered in the handbooks contribute to the overarching goal of doctoral education of the ACS study.[6] Also, this may help faculty or advisors to align their assessment tools toward the learning goals, as well as teaching and learning methods to ascertain that these goals are achieved. This would overall likely benefit prospective, new, and continuing students (especially first-generation and PEER students).

■ LIMITATIONS

According to US News & World Report, there are 211 chemistry programs in the US. Even though there are other rankings, the ranking by the US News & World Report was utilized in this study. A recent study reported an estimation of

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196 doctoral programs found in the US.[10] This is not consistent with the 211 chemistry doctoral programs in the US News & World Report ranking. The ranking by US News & World Report may include other chemistry departments not considered as autonomous chemistry programs in the US. Hence the grouping of the chemistry departments into "top 20", "middle 20", and "bottom 20" may be affected. This paper assumes that handbooks are the only (or primary) source/document for which doctoral education in chemistry can communicate their learning goals. However, we acknowledge that other places such as verbal conversations, advisors, Graduate School policies, etc., can also be sources that communicate learning goals. Backward design typically involves proposed learning goals with aligned learning outcomes (assessment tools), teaching and learning strategies aimed to achieve the goals.[20,24] We acknowledge that some aligned teaching and learning strategies and assessment tools were mentioned in the handbooks, but for this study, we focused only on the learning goals of the chemistry doctoral programmatic elements in the graduate student handbooks.

CONCLUSIONS

It can be said that the graduate student handbooks of chemistry doctoral education may not have been designed based on the backward design due to deficiency in the learning goals of the key programmatic elements of doctoral education in most of the handbooks. While this is not formally a detriment, prior evidence from backward design research suggests that including explicit learning goals and outcomes could improve student experiences and outcomes.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00062.

> Details of the Figure 2 (Appendix A), Table S1 has learning goals, codes, and descriptions, Table S2 has learning goals and examples, Figure S1 has percentages of the number of learning goals per element, and Figure S2 has raw number of chemistry departments broken down by each element (facet) (PDF, DOCX)

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Notes

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