Scientific Authorial Voice: Incorporating Explicit Instruction in Undergraduate Chemistry Courses

Emma L. Becker

College of Arts and Sciences, Liberty University

Author Note

Emma L. Becker

I have no known conflict of interest to disclose.

Correspondence concerning this article should be addressed to Emma L. Becker at [redacted]

Abstract

The effective development of undergraduate chemistry students for success in professional and academic careers involves emphases on content knowledge and on writing and authorial voice. Unfortunately, most undergraduate chemistry instruction wholly neglects writing and authorial voice instruction in favor of content knowledge instruction. This results in the development of chemistry students who know the content of their field but not how to communicate that knowledge or how to enter the chemistry discourse with their own research. This integrative review identified 71 pieces of scholarly literature and synthesized these sources to reconceptualize writing instruction in undergraduate chemistry and propose explicit instruction on scientific authorial voice as a solution. The review identified three main themes, focusing on the inclusion of explicit instruction alongside content-area instruction, the social and process-related elements of effective explicit instruction, and core values of strategies for explicit instruction highlighted in the literature. The findings of this research indicate that explicit instruction on scientific authorial voice may be a solution to the lack of writing instruction in undergraduate chemistry courses and call for further research to ground these findings in qualitative empirical research and test them in undergraduate chemistry classrooms.

Keywords: scientific authorial voice, undergraduate chemistry, explicit instruction, writing instruction, chemistry discourse

Table of Contents

Chapter 1: Introduction

Professional scientists are expected to be both well-versed in content knowledge and adept in writing skills if they are going to contribute to their field's discourse successfully. This dual requirement is not reflected in the training of undergraduate students, who receive an education heavily focused on content knowledge with little mention or practice of writing skills. This research uses an integrative literature review to propose explicit instruction in scientific authorial voice to resolve this inadequacy. To introduce this research, this chapter will first consider the unachieved goals of undergraduate science education. Then, after identifying and describing these unachieved goals, this chapter will discuss the research aim and questions. Finally, this chapter will conclude with a discussion of the definitions used in and delimitations of this research.

Background and Significance

Beginning at the undergraduate level, science education exists to effectively train students to enter the science field in a professional capacity. This goal holds true for scientists in any field, from histology to inorganic chemistry, and in any type of position involving science, including educators, research scientists, physicians, laboratory technicians, or other professionals with scientific technical skills. Regardless of position, the professional scientist's career is comprised of two components. The first is content knowledge. This component is well-established and even intuitive to any understanding of the sciences. Scientists must have scientific content knowledge to do their job. This component of a professional science career gives the scientist the role of a researcher. The second component, engagement with the scientific discourse, is less commonly discussed in scientific circles but no less integral to a professional science career. Because this component primarily involves writing, it is described as the author role. Because students entering the science field in a professional capacity must be

prepared to fill both the researcher and author roles, the goal of science education must be to sufficiently prepare students in both categories.

The efficacy of science instruction must be measured by its success in attaining this goal. Effective instruction must consider the development of student scientists' development as researchers and authors. In other words, instruction must balance instruction in both content knowledge and writing in order to effectively prepare students for their professional careers. However, research and experience show that this balance does not exist. Instead, most science education programs emphasize only the content knowledge aspects of the scientist's role. The scientist as an author is largely ignored in both teaching and assessment.

This neglect of the scientist as an author results in undergraduate degrees that regularly produce science students unprepared for their role as authors. Many chemistry students find that they receive almost no preparation for the communication elements of their careers. The few who do receive instruction in this area often find it in the form of technical writing courses that deal primarily with oral and poster presentations rather than writing, and any writing instruction provided in content courses primarily emphasizes formatting rather than stylistic elements such as authorial voice. This significant gap in instruction plays a major role in producing science professionals, chemists and otherwise, with substantial content knowledge but little to no training regarding the communication of that knowledge and their associated entrance to the professional scientific discourse.

Scientific authorial voice is one of the most critical components of written scientific communication and entry into the professional scientific discourse. Scientific authorial voice is, simply put, the way a scientist "sounds" when they write. Despite the lack of a concise definition, scientific authorial voice is broadly understood to encompass how an author presents

themselves in their writing and how they engage with both the content of their writing and the larger conversation in which they write. Scientific authorial voice is informed by the customs and standards of the author's field and discourse and driven by the guidelines put forward by the most prominent academic journals in the field and the most vocal instructors of and experts in scientific and technical writing.

A well-developed scientific authorial voice is essential for science students who wish to enter the larger scientific discourse as professionals. Because scientific authorial voice is so integral in the success of science students in further academic and professional settings, its instruction is imperative for science education that seeks to prepare students to be well-rounded professional scientists who are authors in addition to researchers. Unfortunately, scientific authorial voice is widely neglected in undergraduate chemistry instruction.

Research Problem, Aims, and Design

Simply put, the problem identified and addressed by this research is the lack of instruction regarding writing and scientific authorial voice in undergraduate chemistry courses. These courses emphasize content knowledge to the exclusion of scientific authorial voice instruction, resulting in graduates being unprepared to enter the chemistry discourse in graduate school or their professional careers. This study aims to identify in the literature whether incorporating explicit instruction on scientific authorial voice in undergraduate chemistry courses would resolve this stated problem. Using an integrative literature review methodology design, this study will examine literature regarding optimal means of instruction in scientific authorial voice, teaching writing and scientific authorial voice in undergraduate chemistry courses, and rationale and recommendations for incorporating explicit instruction in these courses. The research questions for this study, explored further in the methodology chapter, were as follows:

1. How does the undergraduate chemistry community understand and define scientific authorial voice?
2. How well do current and past methods of teaching scientific authorial voice prepare undergraduate chemistry students for their graduate and professional careers?
3. How could explicit instruction be used for teaching scientific authorial voice to undergraduate chemistry students?
4. How can undergraduate chemistry instructors be equipped to teach scientific authorial voice more effectively?

This study involved a database search of applicable literature to identify answers to these questions and propose explicit instruction to solve the problem identified at the beginning of this section.

Definitions and Delimitations

In the context of this research, "science" is defined as the fields that comprise the hard sciences such as biology, chemistry, and physics. The soft sciences, which include the behavioral sciences and the humanities, are not the focus of this project because the authorial voices of these discourses are vastly different from those of the discourses in the hard sciences. Additionally, while science in this sense is closely related to the other fields in the STEM category (technology, engineering, and mathematics) in terms of culture, content, and even authorial voice, these other three fields were excluded from this research's conclusions. Despite this exclusion, insights generated from research in these fields, especially engineering, were found to apply to this research and were thus included.

As an additional delimitation, this research focused on chemistry to the exclusion of the other hard sciences. This choice allowed for more specific research to be identified in the

integrative review and because authorial voice varies considerably even among these closely related fields due to differences in the conventions of each field's discourse. Including even biology along with chemistry would complicate the definition of authorial voice and the discussion of how scientific authorial voice can be best taught via explicit instruction. Thus, while principles were drawn from research in any STEM or hard science field for the purpose of this project, the specific field in focus here was chemistry, and all insights were discussed in terms of their applicability to undergraduate chemistry education and discourse.

The intended audience for this research is chemistry instructors at the undergraduate level. These instructors teach undergraduate students, most of whom plan to attend graduate school in some capacity to enter the field as professional chemists. For most of the students in these instructors' courses, research is a daily activity in their undergraduate career; if it is not, they anticipate it will play a major role in their graduate degrees. Because these instructors' teaching methods inform the skillsets of their students, these instructors must learn how to effectively train students in scientific authorial voice within the context of the chemistry discourse.

Chapter Summary

This chapter identified the problem examined in this research as being the severe lack of instruction on scientific authorial voice in undergraduate chemistry classrooms. To accomplish the primary goal of science instruction by training science students to be both researchers and authors, this lack must be addressed. Using an integrative literature review, this study examined existing literature to determine the potential effectiveness of explicit instruction in scientific authorial voice to increase the quality of undergraduate chemistry instruction. This research focused on undergraduate chemistry and drew context from other hard sciences and provides

recommendations for the implementation of proposed solutions by undergraduate chemistry instructors.

Chapter 2: Review of the Literature

An understanding of authorial voice and its past and current pedagogy is needed before a discussion of introducing explicit instruction as a solution to lacking authorial voice instruction in undergraduate chemistry courses. This understanding is integral for the chemistry instructor considering the integration of more writing instruction in their courses because few chemists have a robust understanding of the writing concepts they are teaching, especially when it comes to authorial voice. For composition instructors collaborating with chemists in this endeavor, a fundamental discussion of authorial voice is just as important because teaching authorial voice to chemists requires a relearning of authorial voice in the context of a unique discourse.

This chapter aims to provide this fundamental discussion, first touching on definitions of authorial voice and the literary and pedagogical schools of thought to which this paper belongs. The uniqueness of scientific authorial voice in the context of academic authorial voice will also be described, followed by an analysis of the history of authorial voice pedagogy in chemistry and the sciences. This discussion is designed to bring readers up to speed, so to speak, on scientific authorial voice instruction as it stands and prepare readers for further discussion of explicit instruction of scientific authorial voice in undergraduate chemistry courses.

Definitions of Authorial Voice

Authorial Voice

On a superficial level, authorial voice is a collection of writing conventions. More specifically, authorial voice is the written components of an author's identity and the style that convey the elements of an author's actual voice as if they were speaking instead of writing (Mhilli, 2023). However, authorial voice encompasses more than just the style of an author's writing. Authorial voice, on a broader level, is the fundamental way authors construct meaning in their writing to create and communicate knowledge in their field (Hyland & Guinda, 2012).

Regardless of the elements of authorial voice that an author chooses to utilize, those elements position them relative to their knowledge and audience and give meaning to facts and evidence that would otherwise be nothing more than a list of facts and evidence. Writing with voice is not an option for authors. Even when authors think they are choosing the voice-less way, they have opted for a specific version of voice that attempts to hide within the writing (Hyland & Guinda, 2012).

While the above description may seem clear and straightforward, authorial voice is actually a vague concept that literature on the topic describes in myriad ways. Authorial voice is described on a spectrum of individual, social, and dialogic dimensions. Other authors see voice as either individualized and chosen explicitly by the author or resulting solely from the writer's interactions with readers and their discourse. Still others understand authorial voice to exist on an epistemological continuum from personal to social constructivist to social constructionist (Hyland & Guinda, 2012). The purpose of this section and this paper is not to reinvent the wheel in an attempt to redefine authorial voice or to create a separate literature review for this discussion. Excellent papers exist to serve this purpose (Mhilli, 2023; Stock & Eik-Nes, 2016). Instead, this section examines the fundamental tenets of authorial voice to understand scientific authorial voice and how it can be most effectively taught in the undergraduate chemistry classroom.

Authorial voice as an idea first appears in the ideas of the Greek philosophers, where it was linked to personal identity. In other words, most Greek philosophers understood a person with a good voice to be a good person, and vice versa. However, others began to realize that voice can be intentionally manipulated for effectiveness, related to the ideology that informed Aristotle's *ethos*, *pathos*, and *logos* (Elbow, 2007). In the ancient world, then, voice/authorial

voice was taught as a component of rhetoric, a means of persuading others or expressing a point effectively. However, this original conception of voice was in the context of spoken communication and thus lacked much of the intricacy of authorial voice as we understand it today.

Voice was first emphasized as an element of writing in the 1960s. In this era, the goal of authorial voice was to allow for greater individuality and decrease oppression (Elbow, 2007). Being true to oneself was the core message of authorial voice in this era, and authors were strongly advised not to write with a voice that was not genuine to their identity (Mhilli, 2023). A shift toward a more social view of voice did not occur until the end of the 1900s and even into the early 2000s, when a further shift toward a dialogic perspective that combines individual and social elements occurred (Mhilli, 2023). This shift in recent years has led to an understanding of authorial voice as an equilibrium between individual and social elements of authorial voice and the author's identity as represented by that equilibrium (Matsuda, 2015).

Perspectives on Defining Voice

The nature of authorial voice must be established to understand authorial voice as a principle of reading, writing, and knowledge construction. On an abstract level, three fundamental perspectives guide our understanding of authorial voice as an abstract concept: the individual, the social, and the dialogic. The individual perspective understands voice as being solely or at least primarily connected to the author's identity, their "uniqueness, or voice as a kind of individual imprint on a text" (Hyland & Guinda, 2012, p. 35). The emphasis in this perspective is on finding one's voice as an author, and research written from this perspective is primarily concerned with having one's voice as an individual suppressed or elevated (Mhilli, 2023). Voice from an individual perspective is concerned with being authentic and committed to

the truth of the things that one is writing, and it is based on identity and a high level of achievement in language skills (Sperling & Appleman, 2011). Authorial voice is classically understood from this perspective as a quality that one possesses based on a static identity, although this element of voice fell in popularity after the 1980s and is less prominent in linguistic discussions in a more modern context (Mhilli, 2023; Sperling & Appleman, 2011).

In contrast to the individual perspective, the social perspective sees authorial voice as defined primarily by the groups to which the author belongs or is connected. Viewed from the social perspective, voice cannot exist in isolation. To use the example of an author in the science field, by adhering to the principles of the genre of science writing, the author "takes on the discoursal identity of a scientist…depending on how closely traditional values and norms are adhered to" (Hyland & Guinda, 2012, p. 38). The same is true for an author writing in any genre: by following the patterns of the genre, the author becomes a scholar in that field, or discourse. This rule holds outside the bounds of academia as well. For example, an individual writing on an ultra-conservative Facebook page becomes a member of that community by adhering to the genre rules of that community.

The dialogic perspective of authorial voice developed as an extension of the individual and social perspectives. Dialogism, in terms of authorial voice, interprets authorial voice as the result of the interaction between the writer and their social context, which includes the abstract community element as well as the more tangible "reader" (Hyland & Guinda, 2012). By combining identity and community, the dialogic perspective is interested in how ideas and their expression are formed through interaction and expression.

The interaction between internal creativity and external society has been eloquently described as a spinning circle (Schmit, 2022). Social conventions pull the writer toward the

center of the circle with a force like centripetal force. Individual creativity pulls writers out toward the edges of the circle and toward their own way of doing things that follows their individual acceleration, to stick with the physics metaphor. The pulls in from conventions and out from creativity shift the author along a continuum of voice choices that make up their own authorial voice in the context of their discourse.

Perhaps, though, a more accurate description of this interaction would have a more 3-dimensional design because the author's current cultural setting is not the only pull "in" that the author experiences. The culture and discourse in which an author has grown up also impact their authorial voice, especially when new academic discourses deviate significantly from the original cultural setting or personal development challenge previously adhered to conventions (Schmit, 2022). This interaction between current and past discoursal conventions behaves like multiple centers of the circle that authors are pulled toward, or, to use a 3-dimensional model, like planets in space pulling authors into their orbits or toward them using gravity. Whatever the analogy, authorial voice is based on both identity and community in the dialogic perspective, and this interaction over time allows authors to write in specific contexts and with specific voices.

The dialogic perspective will form the foundation of this study's discussion of authorial voice in undergraduate chemistry courses because of the significant portion of the literature that emphasizes the interaction of collaboration with personal development in creating and using authorial voice in the chemistry discourse. This research will also be based partly on the theories of academic literacies and English for specific purposes (ESP). In keeping with the tradition of academic literacies, this research will consider students' experiences in the areas described (Lillis, 2014). While this research will not be an ethnography, as many works in the academic

literacies field are, it will identify literature that does function with ethnographic goals and use these findings to provide depth to the claims of this research.

Because of the emphasis of ESP on the reason for which a student learns English, this theory is particularly useful in this research, as chemistry students are learning to use English in a new setting. While ESP was initially designed to teach English to native speakers of other languages, its principles of text-based genre analysis can be beneficial to learning to write in a new discourse. However, the more social components of academic literacies are more central to the interpretations presented in this research than the textual elements of ESP.

Linguistic Theories of Voice

Based on this abstract conception of authorial voice, the following section will discuss more concrete theories. The four theories discussed below are not exhaustive but were simply chosen based on their ability to demonstrate the varied ways of understanding and describing authorial voice. Many more theories exist, and those listed here are not described to their full extent due to the limited scope of this chapter and the focus of this paper on authorial voice instruction rather than theories. Discussion of these theories serves as a foundation for a deeper understanding of authorial voice rather than a wholistic analysis of the field of authorial voice.

The primary linguistic theory of authorial voice is the principle of stance and engagement (Hyland, 2005; Hyland & Guinda, 2012). Stance describes how authors present themselves and their involvement in their own writing. The most well-known aspects of stance are hedges and boosters, which express uncertainty and certainty, respectively. Stance includes attitude markers, self-mentions, evidentiality, affect, and presence. Regardless of linguistic expression, stance as an element of authorial voice is closely related to the rhetorical and Aristotelian idea of *ethos*, especially the component of *ethos* known as *aretai*: the character and values that guide the social

norms of the field (Hyland & Guinda, 2012). The other component of this linguistic theory of voice is engagement, which describes how authors relate to their readers (Hyland, 2005). Engagement includes linguistic elements such as personal pronouns referencing readers (e.g., you, your, we), directives, questions (usually rhetorical and answered immediately), appeals to shared knowledge, and personal asides.

While stance and engagement represent a linguistic theory designed to describe authorial voice specifically, other theories provide larger frameworks for understanding language and define elements of authorial voice based on these frameworks. One such theory is systemic functional linguistics, described as "complexes of evaluative choices that interact in an unfolding discourse" (Hyland & Guinda, 2012, p. 67). Systemic functional linguistics relies on the idea of instantiation, which is a scale of meaning and evaluative choices. All choices of authorial voice within this system are guided by an evaluation of how to construct and present meaning, which includes an analysis of many of the elements of voice, including engagement, projection, modality and sometimes negation, counter-expectancy, attitude, polarity, inscribing vs. invoking, affect, appreciation, judgment and graduation (Hyland & Guinda, 2012).

A third system for describing authorial voice is legitimation code theory, which uses the idea of a language of legitimation that makes a claim to legitimacy (Maton, 2016). These languages work to define status and credibility. Legitimation code theory describes how the "rules of the game" are created and how the unspoken rules of a discourse or a community are made visible. Legitimation code theory allows linguists to distinguish between epistemic relations (content) and social relations (sources and engagement with those sources).

An example of these relations is the knowledge and knower codes (Hyland & Guinda, 2012; Maton, 2016). In the knowledge code, epistemic relations are more significant than social

relations, making the content that the author knows more important than their identity. The knowledge code works well with less visible authors and sources. In contrast, the knower code emphasizes the author's identity and connections over the content, which works well for authors who need to be more visible and depict how they think rather than what they know. Interactions between these two codes in any social context, including academia in general and science in particular, can generate contradictions and changes in the codes, which can all be intentionally utilized by authors for specific purposes.

Finally, authorial voice can be understood in the context of disciplinary metadiscourse, which describes how the author engages with the fact that they are writing and that someone is reading what they have written. In other words, disciplinary metadiscourse is "commentary on a text made by its producer in the course of speaking or writing" (Hyland & Jiang, 2018, p. 18). Disciplinary metadiscourse focuses not only on the author's style but also on the way the author writes with the reader in mind and, in addition, the way the reader reads with the author in mind.

The four frameworks described here are by no means exhaustive and are much more complex than the scope of this paper allows for a discussion of. Additionally, these frameworks and others not mentioned here are not mutually exclusive. Instead of focusing on only one framework, this paper utilizes elements from each perspective to inform a discussion of scientific authorial voice and how it might be best taught in undergraduate chemistry courses.

Markers of Voice in Writing

For the purposes of this research, self-mention, uncertainty, and interaction are the most significant measures of authorial voice. These specific markers were chosen as a focus because they are three of the most unique elements of scientific authorial voice. A discussion of each of these markers could constitute their own literature review. Due to the scope of this research,

mentions of these markers here will be brief in light of the sheer amount of information that exists concerning their definitions and use in authorial voice, academic authorial voice, and scientific authorial voice. These brief descriptions serve as introductions to these elements of authorial voice in these areas.

Self-mention relates to the author's visibility in their own writing. The most commonly discussed forms of self-mention are passive voice versus active voice and personal pronouns, specifically first-person pronouns, as well as grammatical constructions that allow for abstraction that hides the author (Feng & Hyland, 2021; Wang & Hu, 2023). Self-mention modulates textual clarity and author visibility in writing, both vital elements of authorial voice.

Uncertainty serves to mediate the association of the author with their claim. Self-mention does play a role in the moderation of uncertainty, but because of its significance to scientific authorial voice specifically, which will be discussed later, self-mention is separated from the moderation of uncertainty in this paper. Uncertainty is primarily moderated using uncertainty markers, an important subset of which are the subjectivity uncertainty markers. These markers are self-mentions and other linguistic constructions used in specific ways to convey the author's level of certainty and include personal pronouns, adjectives, and adverbs that refer directly to the author (Riccioni et al., 2021). Uncertainty markers are closely related to hedging versus boosting and functionally include various language elements that can alter the author's seeming confidence in their content.

Self-mention and uncertainty relate to the author's relationship with their text. In contrast, the final marker of voice in writing that this paper will discuss is interaction, which deals with the author's relationship to their readers and discourse. Interaction is defined based on all linguistic theories of authorial voice as an author's engagement with the discourse in which they

are writing. Reader mention, projection, and literacy are the components of interaction that the literature primarily mentions. These elements work together to bring authors and their texts either closer to or farther from the readers and the discourse.

Academic Authorial Voice

Depictions of *academic* authorial voice largely depend on the social perspective of voice because one's discourse informs the authorial voice choices that one makes when writing within that discourse. The goal of academic authorial voice is to create credibility for oneself as an author and for one's ideas in the context of one's field and academia as a whole (Hyland, 2002). Because of this, academic authorial voice is primarily concerned with self-mention, of the elements listed above. Of course, specifics of these elements vary by discipline, but academia overall also exhibits trends concerning authorial voice in these categories.

Historically, academic authorial voice has placed great value on keeping authors invisible. This value has heavily emphasized the use of the passive voice, third person, and objective statements. Together, these components represent self-mention, which is officially frowned upon in most academic fields (Hyland, 2002). Editors have been known to reject papers simply because authors included self-mention (Webb, 1992). The argument for such rejection is that self-mention constitutes subjectivity. First-person pronouns, especially singular ones, are seen as particularly subjective, out of place in an academic setting, and even arrogant and overly assertive (Devlin, 2016). This avoidance of self-mention at all costs is taught formulaically as a set of rules to follow that leave little room for "intelligent choices" (Devlin, 2016, p. 35). This heavy emphasis on the social view of authorial voice leaves no room for individual voice or voice based on personal identity.

Instead, any identity expressed in academic writing must be focused on credibility communicated via other means (Hyland, 2002), and this expression can only occur after an

individual has engaged in positioning over time to determine how they fit into the discourse of their field. Positioning the author within the discourse at the appropriate cost to their authorial identity is the primary rhetorical task of authorial voice in academia (Yasuda, 2022). Instruction on academic authorial voice is primarily made up of an insistence on avoiding self-mention.

Research suggests, however, that this dogma may be shifting slowly in response to changing practices among experts. For example, research in the early 1990s recommended a switch toward greater use of first-person pronouns in qualitative research under the condition that personal judgments made by the author are supported by the evidence presented in the paper to avoid subjectivity (Webb, 1992). The shift toward self-mention is recommended for rhetorical functions (e.g., identifying contributions, navigating transitions in a paper, making statements and claims, and positioning the author) and to increase clarity in grammatical forms (Walková, 2019).

Despite the trend toward greater self-mention in academic writing and even in composition research, self-mention in academic writing has remained very low. Data collected in 2015 from research abstracts across chemistry, computer science, social sciences, and medicine from various countries indicated that first-person singular pronouns were seldom used in abstracts, while first-person plural pronouns were used relatively commonly (Kim, 2015). This trend likely continued in the rest of the paper and indicates that self-mention, especially of the author as an individual rather than a nameless “Author” using the Royal We, is still generally avoided. Based on this data, Kim (2015) recommends that authors at any level limit themselves to no more than three uses of first-person pronouns in the abstract of an academic paper to guarantee acceptability in academic circles. Curriculum seems to follow this recommendation and often enforces it with unprecedented intensity.

Despite this firm stance in favor of author invisibility and subsequent minimization of self-mention, the most expert authors in each field will likely reference themselves using personal pronouns in their published writings (Hyland, 2002). Students have been demonstrated to use self-reference dramatically less than experts due to the rigorous campaign against this element of voice in academic instruction. When students occassionally do use self-mention, they usually aim to enhance explanation rather than state an opinion; experts' usage statistics follow the opposite pattern. Avoidance of opinion stating allows students to decrease their association with their statements and stands in stark contrast to the practices of expert writers. While experts likely began their careers as students following the same rules about author invisibility, they stray from this dogma as they engage with the discourse throughout their careers, indicating a potential disconnect between instructional methods/content and actual discourse practices. This potential disconnect may be supported by studies of self-mention utilization in L2 writers in comparison to native English writers, although the correlation has not been verified in this case (Hyland, 2002; Kim, 2015; Moradi & Montazeri, 2024; Walková, 2019)

Regardless of this disconnect, the fact remains that students are taught that good academic authorial voice necessitates the avoidance of self-mention in the form of first-person pronouns (and personal pronouns in general), as well as other elements of self-mention, such as the active voice. Proponents of this perspective argue that decreased author visibility allows for increased objectivity. However, excluding self-mention does not guarantee objectivity (Devlin, 2016). Other elements are at play, including gender, funding, sponsorship, and other contributors. In addition, other elements of authorial voice add to the level of subjectivity in writing and are even integral to the writer's ability to make claims and substantiate them (Yasuda, 2022). Avoiding self-mention or any other element of voice does not necessarily avoid

subjectivity, despite the pedagogical dogma to the contrary, and perhaps avoiding subjectivity is less significant than academia has assumed it to be.

Scientific Authorial Voice

Similarly to academic authorial voice, scientific authorial voice operates with the goal of credibility. However, the severity of this goal is significantly more all-encompassing in the sciences. The discourse in the chemistry field is primarily concerned with evidence rather than engagement. The main social norms (or *aretai*, as discussed earlier in the context of Aristotle's work) in the science discourses are communalism, universalism, disinterestedness, organized skepticism, and originality (Elbow, 2007; Hyland & Guinda, 2012). Together, these social norms create a discourse that values the free sharing of ideas, repeatability of methods, total separation of research from personal goals, profound skepticism, and a reliance on previous work solely as a springboard for new findings.

Adherence to these social norms is required for a credible scientific authorial voice. No amount of significance or impact in one's research can propel one to a prestigious position within the community in the absence of this adherence (Hyland & Guinda, 2012). Hyland (2005) explains this scenario, saying, "In claiming a right to be heard, and to have their work taken seriously, writers must display a competence as disciplinary insiders" (2005, pp. 175–176). While this is true in any field, status as a disciplinary insider is even more significant in the sciences because the social norms described above are integral not only to science writing but also to science itself. These norms represent values that drive even the research that the written voice represents.

While this integral connection between values, research, and authorial voice may seem straightforward to the composition instructor, scientific undergraduate education often explicitly states that credible scientific writing has no voice. Instead, scientific writing is taught as an

objective and impersonal element of writing that almost exclusively keeps authors invisible (Yasuda, 2022). In other words, scientific writing is an exaggerated version of general academic writing. The term "voice" in the sciences is often assumed to be the same as author subjectivity and is often associated with monetary or personal bias that clouds the credibility and reliability of findings (Hyland & Guinda, 2012; Yasuda, 2022). Avoiding subjectivity and bias in this understanding requires the avoidance of "voice."

However, even avoiding typical voice elements represents a choice of authorial voice because voice is simply a collection of writing conventions. Writing with an authorial voice does not mean having a more personable writing style; instead, it means having a style of writing at all. By making choices to avoid personality and the associated subjectivity, scientists choose a specific version of authorial voice that distances them from their writing in the eyes of their reader but is an authorial voice nonetheless. This misconception inextricably links authorial voice with personality and subjectivity in the scientific discourse, leading to a total avoidance of any discussion of voice or writing style.

In addition, seeing scientific objectivity as the avoidance of authorial voice is mmisguided because authorial voice has been intimately connected to scientific writing since the beginning of the Western education tradition. In fact, authorial voice itself originated in the sciences during the transition of education from an oral to a written framework (McGann, 1997). This transition gave rise to what we now describe as literacy: knowledge decontextualized by separation from the author and the reader by time and space (McGann, 1997). Fundamental literacy includes simple reading and writing and all the elements thereof, including voice; derived literacy involves a more complex understanding of "knowledgeability, learning, and education" (Norris & Phillips, 2003, p. 224) that emphasizes content knowledge. Both types of

literacy are integral parts of written knowledge. The sciences developed at the same time as the development of literacy in the Western academic tradition and was reliant on written forms of communication. The development of science, written communication of knowledge, and literacy was so intertwined that the three became indistinguishable from one another.

Because of this unique interdependence of written scholarship and the sciences, authorial voice in its scientific form is so closely connected to science as a field and a discourse that science simply cannot exist without scientific authorial voice (Norris & Phillips, 2003). Whatever science instructors might argue, scientific writing is not and should not be "voiceless;" rather, it should depend on a unique set of authorial voice patterns that accomplish the goals of scientific writing while aligning with the values of the scientific discourse. These patterns are described throughout this paper as "scientific authorial voice."

Self-Mention turned Self-Effacement

As with general academic authorial voice, scientific authorial voice seeks to eliminate author visibility and the social elements of writing so that all scientists write as if they were a single author, conceptualized as the greater scientist (Yasuda, 2022). For example, chemistry uses less self-mention in the form of first-person pronouns than other disciplines studied across cultural boundaries (Kim, 2015). The passive voice is so commonly used in the sciences to maintain a decreased connection to human actors that it has even been described as "a standard feature of scientific writing" (Banks, 2021, p. 37). First-person pronouns are rarely used in scientific writing, although some authors have identified a more progressive trend in recent years toward a decrease in the use of passive voice and a greater willingness to use first-person pronouns (Banks, 2021). Much more research is needed to determine whether more progressive trends are valid and indicative of future shifts.

Shell noun phrases, another element of self-mention, have demonstrated a decrease in frequency of use over the last 40 years, at least in the chemical engineering field (Wang & Hu, 2023). This trend could imply a shift toward increased author visibility that Wang and Hu (2023) dub an "author-intrusive and interactive writing style" (2023, p. 187). The decrease in shell noun phrases can make writing feel less exclusive and less reflective of high academia, which increases the accessibility of the writing to the layperson. However, the decrease in shell noun phrases reported here is only in a few select categories.

Contrary to these findings concerning shell noun phrases, some authors report a striking increase in metadiscursive nouns from 1965 to 2015 (Feng & Hyland, 2021). This finding is not necessarily incompatible with the reported trends regarding shell noun phrases. The disappearance of shell noun phrases in the sciences may allow for greater author visibility, while the increase in metadiscursive nouns may allow for greater accessibility. These changes would contribute to the broader goal of making scientific writing more accessible and less disciplinary-discourse-specific. Much more research is needed to verify any overall trend toward increased author visibility in the science discourses based on shell noun phrases or metadiscursive nouns.

Certainty

Certainty is perhaps the most essential value of authorial voice that scientific authors consider. Both overcommitting and under-committing can destroy an author's credibility. To mediate both errors, scientific authors must use "measured claims…calibrating the probability and degree of certainty" with great precision (O'Hallaron & Schleppegrell, 2016, p. 65). Uncertainty is most heavily utilized in the introduction and discussion sections of papers (Yang et al., 2015). Medical research article writers specifically use a characteristic tone that is "cautious, reserved, and objective" (Yang et al., 2015, p. 5). Scientific authors balance high and

low levels of certainty to avoid stating their own opinions by using high-certainty statements while also avoiding close ties with an idea that does not last by using low-certainty statements (Riccioni et al., 2021). Both certainty levels also balance the audience's authority with the author's credibility (Yang et al., 2015).

By far, hedges are the most significant constructions in the science discourse to mediate uncertainty. Hedges are heavily used in science writing as a means of guarding against future evidence that disagrees with the paper (Hyland, 2005); the facts might be proved wrong, but the author's credibility is not destroyed because hedges were used from the beginning to indicate that this might happen. The heavy use of hedges in scientific authorial voice aligns with the positive valuation of disinterestedness and organized skepticism in the field (Hyland & Guinda, 2012).

Hedges are also related to graduation, allowing the author's confidence level in a claim to be communicated. Graduation allows authors to avoid making judgments on the "goodness" or "badness" of a claim and instead focus on their level of confidence in the claim (Hyland & Guinda, 2012). Scientists often use graduation to maintain politeness while making claims with significant meaning. The meaning-making structure in the scientific discourse would not function without hedges, graduation, and their impacts on communicated levels of certainty (Yasuda, 2022).

Projection and Engagement

Projection refers to authors' references to other sources in their writing. The goal of projection in the sciences is to direct readers to another article rather than to engage with that article's content (Harwood, 2009), which aligns with the overall goal of scientific writing. Because of this goal, projection is most often embodied in minimally visible citations that do not

even mention author names in in-text citations (Hyland & Guinda, 2012). Appeals to shared knowledge are not common in the science discourses because readers are expected to have an appropriate level of expertise and be able to grasp references without assistance from the author (Hyland, 2005). By avoiding knowledge of who is connected to a piece of knowledge, scientific authors attempt to avoid personal, subjective, and interested (as opposed to disinterested) elements of writing.

Additionally, authors in the hard sciences rarely cite themselves in their own work, an element of voice that Hyland and Guinda (2012) call "presence." Because of this, authors will rarely include transitions or references such as "As we discussed earlier" or "According to the findings I describe in my last paper." Instead, they would say, "Based on previously discussed data," or simply include an in-text citation to their past paper (Hyland & Guinda, 2012).

While a robust discussion of disciplinary metadiscourse as a means of modulating engagement is out of the scope of this chapter, it must be noted that the elements of this framework have undergone significant shifts in the last fifty years. These trends indicate that scientists have trended toward increased depictions of judgment about the values of claims (Hyland & Jiang, 2018; Yang et al., 2015). However, available studies on these trends are limited in their applicability to the science discourse because they focus on general academia rather than a particular field.

Together, the trends described in self-mention, certainty vs. uncertainty, and projection and engagement tentatively indicate that authors using scientific authorial voice are becoming more visible in their own work, more known for their own work, and engaging with their audience more significantly than was historically expected. Of course, these trends are drawn from published literature in the discourse rather than curriculum or student work and represent

experts in the field rather than pedagogy. This data may be skewed toward expert practices rather than accepted dogma and teaching content, which may be a significant limitation of the existing literature if there is a gap between these two areas, as mentioned previously.

Pedagogy of Scientific Authorial Voice

Definitions and accepted frameworks of understanding authorial voice and scientific authorial voice are critical for solving a lack of preparation in undergraduate chemistry students. However, few steps can be taken without an additional understanding of past and current teaching methods. This section examines standards and practices in chemistry authorial voice education from K-12 to undergraduate courses and describes a pedagogy of entering the chemistry discourse after completing an undergraduate degree based on existing literature.

Historical Trends and Current Standards

From the 1960s to the 1980s in the United States, general authorial voice was taught primarily as a means of expressing identity (Sperling & Appleman, 2011). Literacy became the foundation of authorial voice instruction as this understanding shifted to include more social – and later, dialogic – perspectives on authorial voice. Scientific literacy was established in 1993 as a standard for U.S. students K-12 as a part of the Educate America Act (Goals 2000: Educate America Act, 1994). Current standards for science learning at the K-12 level are based on federal guidelines that have followed this bill, especially the *Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013).

Taken together, these standards rely on derived literacy (learning, education, and knowledgeability) (Norris & Phillips, 2003) and seek to produce students with "sufficient knowledge of the practices, crosscutting concepts, and core ideas of science and engineering" so that these students can "engage in public discussions on science-related issues…be critical

consumers of scientific information related to their everyday lives, and…continue to learn about science throughout their lives" (National Research Council, 2012, p. 9). These standards desire that all students, not just those destined for further science education or careers, leave high school with a basic level of this knowledgeability of science that they describe as "a process of critique and argumentation" (National Research Council, 2012, p. 78) and "a set of practices [in which] theory development, reasoning, and testing are components of a larger ensemble of activities that includes…specialized ways of talking and writing" (National Research Council, 2012, p. 43). Students are expected to develop these skills throughout their K-12 years and carry them into their undergraduate careers.

Interestingly, while these standards heavily emphasize the knowledgeability that students must develop as a part of their literacy, minimal discussion of the reading, writing, and authorial voice that must undergird that knowledgeability is evidenced in the standards. This lack of discussion is because, in science education, the emphasis has historically been on derived literacy and critical thinking rather than on fundamental literacy and the expression of knowledgeability and critical thinking in reading and writing (Norris & Phillips, 2003).

Federal standards, however, do not reach past high school graduation. At the undergraduate level, standards are left up to the school and the industry. Each school has its own somewhat unique set of standards and requirements for coursework. In chemistry, these are somewhat standardized by the American Chemical Society (ACS), the most significant scientific society in the United States. Because of the impact of the ACS, most chemistry education follows the ACS guidelines and evaluates students using the ACS standardized exams for each chemistry course.

Two documents detailing ACS standards for undergraduate chemistry instruction are available. The first is the *Science Education Policy* (American Chemical Society, 2023), which spans 2023-2026 and provides simple guidelines for policymakers who might impact chemistry education. This document does not mention writing, reading, or discourse at the higher education level. This policy mentions literacy in the U.S. Education System section, but only in teaching chemistry as a core subject and ensuring equal access to chemistry education. While these are essential points, they do not refer to scientific writing.

The *2023 Guidelines* (American Chemical Society, 2022) provide a more robust picture of the ACS standards. This document explains the expectations for undergraduate chemistry programs in several areas, including laboratory work and safety, coursework, curriculum design, faculty and staff support, diversity, and departmental infrastructure. The first mention of teaching scientific communication does not occur until section eight, which addresses professional skills and competencies. This section states critical requirements for an approved undergraduate chemistry program:

> The chemistry curriculum must include writing and speaking opportunities that allow students to learn how to communicate technical information: (1) clearly and concisely, (2) in a scientifically appropriate style for the intended audience including non-technical audiences, (3) ethically and accurately, and (4) utilizing relevant technology (American Chemical Society, 2022, p. 24).

This standard represents the most transparent and complete description of teaching scientific writing and authorial voice identified in this research. While “scientifically appropriate style” (American Chemical Society, 2022, p. 24) is still relatively unclear, this description goes far beyond the K-12 regulations in terms of describing effective scientific literacy.

The standards go on to state as another critical component of an approved chemistry program that "communication skills must be explicitly assessed to determine the level of student competency in both written and oral scientific communication" (American Chemical Society, 2022, p. 24). By taking the above standard a step further to require that written and oral skills be evaluated explicitly, this standard requires that reading and writing, in other words, engagement with authorial voice, be taught and assessed in undergraduate chemistry classrooms. Together, these two standards provide a much more complete picture of the writing and authorial voice training students should receive in their chemistry courses than the K-12 standards.

Beyond these standards, authorial voice directives at the undergraduate level are drawn from the journals in which students and instructors would be/are publishing. As most chemistry journals originate from the ACS, the *ACS Guide to Scholarly Communication* (Banik et al., 2020) proves most useful for students. However, this guide is not open access and must be obtained via the library at an institution for student access. Many institutions do not have this capacity. Other journals have their own style guidelines, but none are as comprehensive or oft accessed as those provided by the ACS. Some scientific style books do exist; these are dramatically out of date for the most part, however, and are often not accessible to undergraduate students.

Current Conventions and Their Impact

The above discussion of the historical trends and standards brings us to the current pedagogy of scientific authorial voice. The standards that guide K-12 scientific voice education will be briefly mentioned first because these standards inform what is possible at the undergraduate level and beyond. Next, current practices in undergraduate and graduate schools will be discussed along with their effectiveness in producing chemists who can clearly communicate their knowledge and findings within their discourse and beyond.

K-12 Standards

The emphasis on derived literacy in the K-12 standards described above does demonstrate a positive shift from rote memorization toward critical thinking that allows students to be engaged in the epistemological activities of the classroom (Duggan, 2022) and aims to develop their "scholarly and scientific style" from the youngest possible age (Maguet et al., 2020, p. 805). The authors of the standards state that "reading, interpreting, and producing text are fundamental practices of science in particular, and they constitute at least half of engineers' and scientists' total working time" (National Research Council, 2012, p. 74). This bold statement demonstrates the significance of scientific literacy in K-12 education, but the language of such statements might imply a value of literacy that is too high in general than warranted by the standards' content.

Only one of the practices described in the National Research Council's foundational report (National Research Council, 2012) and utilized in the *Next Generation Science Standards* (NGSS Lead States, 2013) directly involves the details of writing in the sciences. Not only are reading, writing, and authorial voice mostly avoided in the standards, but any reference to these is vague (O'Hallaron & Schleppegrell, 2016). The standards use the term "informational texts," which seems to be broadly defined in the Common Core standards to include texts such as biographies (Maloch & Bomer, 2013; National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010).

Because of this lack of clarity, the standards do not reflect how classrooms operate, even at the elementary school level. For example, teachers evaluating voice, even at the elementary school level, evaluate authorial voice elements in student work in various ways (O'Hallaron & Schleppegrell, 2016). Agreement in the grading of these assessments also varies by grade level,

indicating that expectations of voice change as students develop despite the lack of clarity on what these changes might be.

Some research suggests that elementary students are still taught with an emphasis on the mechanics of writing (conventions and clarity) to the exclusion of authorial voice in instruction (Humphrey et al., 2014). This finding has become apparent from assessment results rather than the standards from which teachers are allegedly teaching. Grade-school-level classrooms also still emphasize the memorization of facts and processes over inquiry and even argumentation, despite the shift in the standards toward a more wholistic perspective of learning science (Sampson, 2012). This discrepancy is evidenced in recent literature discussing teachers' professional development in implementing argument-based learning in their classrooms.

The purpose of this discussion is not to argue whether rote memorization should be included in classrooms or whether argument-based learning is beneficial. Instead, it is to point out that while the existence of the K-12 science standards is a step in the right direction, the brief and vague mention of reading, writing, and authorial voice causes a lack of continuity between the standards and the classroom. Despite the positive changes in the standards, an extreme and problematic focus on content knowledge still exists in K-12 science classrooms (Norris & Phillips, 2003).

Of course, the two components of scientific literacy must go together; the fault at hand would not be remedied by a pendulum swing to the other extreme. However, not seeking a middle ground, even at the elementary school level, constitutes "the risk that students will never fully grasp the point and significance of scientific knowledge" (Norris & Phillips, 2003). Both elements are needed to educate K-12 students in the sciences successfully.

Pedagogy of Entering the Scientific Discourse

Even more significantly, the K-12 overemphasis on derived literacy to the exclusion of robust reading and writing elements such as scientific authorial voice continues into undergraduate curriculum and courses. Students who pursue a science education discover a distinct gap between the expectations of graduate school or their field and the preparation they receive in their undergraduate courses regarding scientific authorial voice and their readiness to enter the discourse (Reave, 2004).

Graduate schools expect students to know how to engage with the field's discourse and manipulate their own scientific authorial voice from their first day. Graduate chemistry students must be self-directed learners, pursuing scholarly activities for themselves, intend to publish and write at a publishable level, require as little direct guidance as possible, be able to translate reading and writing skills from other disciplines into science and the lab, and have excellent problem-solving skills (Dysthe, 2002; Falconer, 2018).

Rather than simply expecting students to be able to write within the genres of scientific writing (report, proposal, etc.) in adherence with convention, graduate schools, and the field expect students to be able to intentionally and strategically manipulate genres (Negretti & McGrath, 2020). As a participant in one study on supervisory relationships in graduate school, one supervisor stated, "It's relatively straightforward to write in a scientific way…but to write really conceptually is quite different" (Ross et al., 2011, p. 22). This conceptual writing refers to the manipulation of genre and the complex values of graduate school for students from their first day. Despite this, graduate chemistry programs affirm strict adherence to genre conventions. Supervisors gatekeep the ability to manipulate genre outside of the conventions (Negretti & McGrath, 2020). Students are expected to be able to manipulate genre and voice to be considered legitimate but simultaneously taught that deviance from normative practices is not allowed.

In addition, students face overwhelming pressure to establish themselves as credible members of their field and discourse. Graduate schools place heavy emphasis on rigorous requirements prior to admittance to the discipline and the discourse. Students must earn the right to be considered “real scientists” and permission to write confidently and boldly.

While students are attempting to learn how to mediate their own discoursal identity in the face of these contradicting messages, graduate schools assume they have already done so. Graduate schools typically assume that students obtained sufficient writing and authorial voice training in their undergraduate courses to equip them to enter the discourse as they enter graduate school (Marchant et al., 2011). Professional settings assume the same and expect students to move forward with problem-solving tasks within the discourse almost immediately upon hire (Appleby et al., 2012). Based on this inaccurate assumption, developmental instruction is not often provided to students in these areas upon entry into the graduate chemistry discourse. Instead, supervisors resolve issues without discussion or explanation (Marchant et al., 2011; Ross et al., 2011). Any instruction is irregular and only provided as needed, even outside the sciences (Badenhorst et al., 2015). The relationship between students and their faculty supervisors is often unclear and difficult to navigate (Ross et al., 2011).

Students entering graduate school in this setting report feeling uncertain, frustrated, hurt, disillusioned, and unsupported in their writing efforts (Aitchison et al., 2012; Ross et al., 2011). Students struggle to position themselves in the chemistry discourse and discover their own identity within the field, a process that is primarily accomplished via the writing process over time. While some students report enjoyment of the thesis or dissertation process, this enjoyment did not come without a long struggle.

However, these graduate and professional expectations are not reflected in the expectations and curriculum at the undergraduate level. Students are expected to pick up discourse skills over time during their undergraduate careers, almost "by osmosis" (Goldsmith & Willey, 2014, p. 7; Whitehead, 2002). This model of learning writing skills is the "traditional assumption" or the "apprentice model" (Gourlay, 2009, p. 181). Faculty seems to assume that as students spend time with concepts, complete their assignments, and interact with faculty members and peers, they will develop their scientific authorial voice with no intentional outside influence. This osmosis-like teaching method assumes that students will learn how to enter the discourse by the end of their undergraduate career with minimal effort from the instructor. Notably, these conventions of teaching (or not teaching) writing and authorial voice in undergraduate chemistry classrooms do not align with the standards put forward by the ACS (American Chemical Society, 2022).

In keeping with this expectation, the emphasis in undergraduate courses is on content, not on writing. The rationale for this emphasis, aside from the assumption described above, is that students who are not yet producing publishable data do not need to be educated on how scientists communicate (Cameron et al., 2015); students will pick up the skills by the time they need them, so no instruction on those skills is needed at this level.

Because of this expectation, any writing instruction in undergraduate chemistry courses almost exclusively emphasizes format guidelines. Writing instruction is entirely technical and skill-based and broadly does not emphasize how to communicate relevance for the future or understand knowledge construction in the field (Appleby et al., 2012). Writing instruction is seen as valuable only for the generation of a product, not for understanding the process of writing as central to the process of learning (Cameron et al., 2015; Goldsmith et al., 2017). These strategies

become an “assessment discourse of writing” (Baker, 2017) that handicaps students as they move to higher levels of education because they are focused on their product and its grade rather than the quality or creativity of their writing or even what it communicates.

Outside of these formatting guidelines, little to no direct instruction in writing exists in science courses. Little evidence exists in the curriculum itself that instructors are working to develop students’ writing abilities (Goldsmith & Willey, 2014). Direct instruction, scaffolding, and other activities that develop students’ skills to complete their writing assignments seem to be completely absent from undergraduate chemistry curriculum. Instructors rarely provide examples of good scientific writing. The stated goals of the assignments do not always match the assignments themselves, even at the level of rubric and assignment instructions; often, stated goals do not exist at all (Goldsmith et al., 2017; Goldsmith & Willey, 2014). While the strict format of science text is often clearly communicated via rubrics and assignments, instruction on implementing that structure in terms of voice is vague, if present at all (Dysthe, 2002). Instructors provide little to no mentorship regarding draft/feedback cycles in producing a paper to scaffold students’ understanding of the process (Gourlay, 2009). Additionally, individual instructors have different values in writing and thus teach writing with a unique emphasis due to the lack of curriculum standards regarding what appropriate style might look like in the chemistry discourse (Goldsmith & Willey, 2014).

Because of the communicated perspective of writing as a formatting exercise and the lack of clarity and instruction apart from that perspective, students see scientific writing and authorial voice in the sciences as being an ideal toward which they must strive (Johansen & Harding, 2013; Whitehead, 2002). Students envision a specific, mysterious, unchanging set of rules and

standards for chemistry writing that they must achieve. The implication is that if they follow the rules and achieve this standard, they will be admitted to the discourse.

Along with the lack of direct instruction and the format-based standards, this student perception stifles creativity, critical thinking, and lifelong learning skills (Johansen & Harding, 2013; Whitehead, 2002). Students are left confused and frustrated, unsure of how to improve their writing, and unclear about what is expected of them. Students report feeling alienated, illegitimate, disengaged, lost, and unsupported (Gourlay, 2009; Whitehead, 2002). Gourlay (2009) emphasizes the in-between nature of this writing situation for students, describing the emotions that it brings up as "indeterminate and unsettling" (p. 185). Students feel overwhelmed and discouraged and describe a lack of confidence and an inability to focus on exploring ideas that form the foundation of the sciences as a field (Johansen & Harding, 2013). Ross et al. (2011) further state that undergraduate students lack the skill of critical analysis to take their writing past the descriptive stage and to the evaluative and conceptual level. Essentially, students exiting the undergraduate chemistry system as it functions now do not feel prepared to enter the chemistry discourse.

The result of the general lack of instruction at the undergraduate level is that entering the discourse in graduate school or professional settings where the ability to engage with the discourse via appropriate authorial voice is considered a given "could best be described as being thrown into the ocean without a life vest" (Falconer, 2018, p. 20). The distinct similarity in the emotional impact of writing and writing instruction that undergraduate and graduate students describe tells the same story twice: students feel and are unsupported in the development of their scientific writing at all levels, and this impairs their ability to effectively engage with the field even when their content knowledge more than suffices. Students leave their undergraduate

careers without the ability to be author-scientists productively engaged in the chemistry discourse.

The statements above are particularly true for oft-excluded groups of individuals, such as women, people of color, individuals from lower socioeconomic backgrounds, and individuals claiming unique gender orientations (Falconer, 2018). Any gap between undergraduate education and graduate expectations for the "average" student (historically, white and male) is exacerbated for students in these other categories. Aside from any political ramifications of these statements, if "average" students report a gap in their levels of preparedness for graduate school and the field, the gap can be assumed to be even more significant for non-average individuals and the need for a solution even more compelling.

Chapter Summary

This chapter reviewed the literature that informed this research by describing authorial voice as a collection of writing conventions that work together to construct meaning and communicate knowledge. After establishing the reliance of this research on the dialogic perspective as well as the theories of academic literacies and English for specific purposes, this chapter described linguistic theories that inform depictions of authorial voice in the literature. The markers of voice discussed in this research are self-mention, uncertainty, and interaction. This chapter then described academic authorial voice and scientific authorial voice, noting the intricacies of the three markers of authorial voice in the sciences in detail.

After these definitions and descriptions of authorial voice and its role in academics and the sciences, the pedagogy of scientific authorial voice was discussed at length. This discussion included practices and standards both at the K-12 level and at the undergraduate level and focused on skills related to entering the chemistry discourse. Historical trends and the

development of standards were discussed, followed by an analysis of currently practiced conventions regarding instruction on scientific authorial voice or the lack thereof. This chapter concluded that assuming undergraduate chemistry students will learn scientific authorial voice by exposure alone does not result in their successful preparation for a professional chemistry career and develops in students a negative view of writing. This conclusion based on a broad literature review constitutes the problem addressed by this research.

Chapter 3: Methodology

This research aimed to propose explicit instruction as a solution to the problem of the lack of preparation for undergraduate chemistry students for their graduate and professional careers in the area of scientific authorial voice. This chapter will discuss integrative review as a theoretical framework for this research based on the guidelines put forward by Torraco (2005, 2016). The integrative review structure was used to draw together relevant literature and, based on that literature, accomplish the aim of this study.

Rationale for an Integrative Review

An integrative review was chosen as the theoretical framework for this research because of its ability to impact the field. The goal of science education is to produce scientists who are adept in both their content knowledge and their ability to communicate that content knowledge. However, only the first is adequately taught in most undergraduate chemistry courses. As a result, chemistry students enter their graduate and professional careers and the chemistry discourse without the ability to use their own scientific authorial voice confidently. This research study proposes explicit instruction as a strategy to lessen that gap by improving undergraduate chemistry education in scientific authorial voice. This research holds great relevance for the field of chemistry; improving undergraduate chemistry education will eventually enhance the field as a whole.

Despite the topic's significance, very few literature reviews on teaching general authorial voice exist. No reviews exist on teaching authorial voice in science classes. And, no reviews exist on teaching authorial voice in a chemistry class. Before further research in this field can occur, a review must be done to synthesize the literature relevant to this topic from the education field of composition and the science field of chemistry. This review will perform this synthesis of information from both the composition and the chemistry fields to propose explicit instruction as

a solution and to direct future research studies that will be able to fill the gaps in knowledge that this study reveals. By allowing the author to collect data related to the topic and utilize it for future research, the integrative review as a theoretical framework functions as a first step toward filling in the identified gap in literature.

The immediate result of the synthesis done in this research is the proposition of an alternative model of instruction of scientific authorial voice: explicit instruction. This proposal alone takes strides toward resolving the identified problem. However, a secondary result of this research is its proposed research agenda. This research functions as a foundation from which this author and others can launch toward further research in scientific authorial voice instruction in undergraduate courses. Because of this impact, made possible by the integrative review framework, this study not only brings to light the gap in literature but proposes future means of eliminating the gap entirely.

This study was conducted through the theoretical framework of an integrative review rather than a simple literature review so that the author could review, critique, and synthesize the literature to reconceptualize the topic (Torraco, 2016). A simple literature review would not allow for this emphasis on analysis, which is integral to the purpose of this research. The results of the synthesis in this integrative review allow for a reconceptualization of what it means to teach writing in general to undergraduate chemistry students and how that can best be accomplished in terms of authorial voice. Without the synthesis in this review's integrative aspect, this reconceptualization would not have been possible.

Methods of Integrative Review

This integrative review was conducted primarily in the form of database searches. Search terms used in this process are listed in Appendix A. Databases used in this research include

Google Scholar, ProQuest, ERIC(EBSCO), JSTOR, Elsevier, and ResearchGate. All literature identified via any of these databases was evaluated according to the following criteria prior to use. The primary qualification for data collection was that a source must be considered *scholarly literature*. This broad term was used intentionally to include books, conference proceedings, essays, peer-reviewed journal articles, and even style manuals, regulations, and published educational standards. This wide range was chosen to capture many types of research on the topic from a variety of perspectives, along with other types of data that might depict expectations and methods of teaching scientific authorial voice. Literature included in this research had to be open access or accessible via Liberty University's Jerry Falwell Library. No date constraints were used because this study sought to collect perspectives from both recent and past literature on the topic.

Literature searches were based on four categories. The first was educational theory, which included pedagogies concerned with explicit instruction for teaching scientific authorial voice. The second was literature from the chemistry discourse on topics such as current and past methods of instruction on scientific authorial voice, the attitudes of instructors and students toward scientific authorial voice instruction, and the specific challenges and needs of the field in this area. Third, educational theory for training and equipping chemistry instructors in explicit instruction of scientific authorial voice was sought. Fourth and finally, literature discussing the impact of scientific authorial voice instruction in undergraduate chemistry courses on student preparedness for chemistry graduate programs and careers was sought.

Criteria for these four categories shifted throughout the study due to the lack of applicable literature for such a specific topic. Teaching methods literature was initially restricted to undergraduate chemistry settings but was expanded to include some graduate and doctoral

science settings and some grade school science settings that allowed for the extrapolation of similar principles. Additionally, literature on educational theory was intended to discuss teaching scientific authorial voice specifically in a general content classroom but was expanded to include teaching writing in general in a science classroom specifically. Literature from the chemistry discourse was broadened to include literature from the biologies, the other hard sciences (including physics), and then STEM in general. Studies of medical school writing instruction and student experiences were also included here, as most medical students primarily studied biology and chemistry in their undergraduate careers. Literature related to equipping instructors was expanded to include teaching STEM instructors how to teach composition topics in general and enhancing collaboration among STEM and composition instructors.

Criteria for literature discussing the impacts of undergraduate chemistry instruction on preparedness to enter the chemistry discourse were expanded less dramatically because much research exists to demonstrate graduate students' and professionals' emotional and practical preparedness to enter the discourse. This literature was restricted to graduate, doctoral, and professional settings exclusively. Much of this literature focused on writing instruction in general rather than scientific authorial voice instruction in specific, and instruction in chemistry was expanded to include instruction in the hard sciences. However, these alterations to criteria had less impact on the type and topic of literature collected than the expansions to criteria in other areas.

After searching for literature using the methods and criteria described above, 71 sources were identified. These sources ranged from 1992 to 2024. A list of journals in which peer-reviewed articles were identified is included in Appendix B. Other types of sources are also included in Appendix B.

After sources were collected, they were assessed for themes based on their abstracts, if they had abstracts; sources without abstracts were evaluated for potential themes based on structural elements such as introductions, topic sentences, titles, or brief readings of conclusions. This initial assessment was followed by a more extensive reading of the source's results and/or discussion sections (for peer-reviewed articles and similarly structured sources) or the entire source (for sources without results and/or discussion sections). Based on this intentional reading, the author took notes on the themes of the source. As notes for each source were synthesized with other sources and their themes in an outline, key themes were identified and notated based on the patterns of themes that appeared in the outline. The outline functionally served as a list of themes and their connections in place of a formal coding process.

Verification of themes was performed in various ways. Thick descriptions were utilized by taking detailed notes before identifying and analyzing themes. These detailed descriptions represented the actual findings of the source so that themes were ensured to be accurate to the sources and not biased by the author’s perceptions. Triangulation was involved via the use of various databases, journals, types of sources, and publishing dates to verify the validity of findings across multiple locations. Data was collected to saturation when all sources returned the same themes. Saturation indicated that the themes identified were representative of all possible data and that no further data collection was required. Additionally, code-recoding was used. This verification method allowed the author to revisit the notes with themes identified to confirm that the themes matched the intent of the original sources. Together, these strategies verified that the themes identified in reading and coding the findings were valid and representative of the literature.

Chapter Summary

This chapter described integrative review as the theoretical framework of this research. Integrative review proved to be the most effective methodology because of its significance for the chemistry field in establishing a foundation for more research to be conducted that works toward a solution to the identified problem. This methodology also made possible analysis and synthesis that formed the basis of a reconceptualization of writing instruction in undergraduate chemistry courses and what current pedagogy and future revisions to that pedagogy might mean for the field. This chapter concluded with a description of the methods used in this research, describing the criteria for the collection of scholarly literature and shifts in those criteria based on available literature.

Chapter 4: Results

The methods above identified 71 sources published across a range from 1992 to 2024. A list of journals in which peer-reviewed articles were identified is included in Appendix B; other types of sources are also listed in this appendix. This chapter discusses in detail the results gleaned from the identified literature. In short, the literature identified a need for increased development of students' writing and authorial voice skills and demonstrated that explicit instruction may be a viable strategy to fill that need.

Three key themes emerged from the literature to illustrate this finding. First, writing instruction, including instruction in scientific authorial voice, must be included in undergraduate chemistry courses alongside content instruction. The inclusion of writing instruction in the field of chemistry is no longer optional because students are suffering from its exclusion. Second, writing instruction in undergraduate chemistry courses must emphasize the social and process-related elements of writing. While grammar and formatting topics are essential, these more rule-based elements of writing are somewhat over-emphasized in the sciences. They must yield to community knowledge-building and the development of students' writing process over time if students are to be successfully developed as both chemists and authors. Third, the literature devotes much discussion to specific strategies instructors can implement to teach authorial voice in their courses. These strategies, along with the common rationale and pedagogical emphases of each, can aid undergraduate chemistry instructors in successfully incorporating instruction on scientific authorial voice in their classrooms.

Writing Instruction in the Sciences

The literature identified in this study overwhelmingly demonstrated that writing instruction in the sciences is invaluable and must be taught alongside content. While this would be true in any content area, the literature emphasized its particular importance in the hard

sciences. Many authors even described the connection between writing and science as so intimate that science cannot exist without writing. Norris and Phillips (2003), for example, state, "Scientific knowledge has an essential dependence upon texts and…the route to scientific knowledgeability is through gaining access to those texts" (p. 231). In other words, spoken communication alone does not suffice to cope with the sheer complexity of scientific thought. Written communication is required because intricate content knowledge in the sciences must be transmitted across space and time to maintain the progress of the field, a task to which oral communication cannot measure up. The scientific discourse and written communication are inextricably linked, making instruction in the writing conventions of the discourse a necessary part of a science education.

Scientists must be trained to use and understand writing conventions and content in tandem to comprehend and communicate scientific thought effectively. This duality forms the basis of scientific literacy because understanding and using scientific writing conventions are both integral to understanding and interacting with scientific content. Scientific knowledge, therefore, depends on the writing conventions of the field and primarily on scientific authorial voice. When either writing conventions or content knowledge are neglected, scientists have no practical way to communicate knowledge with others: without its relevant communication, content knowledge ceases to be meaningful. If writing conventions and content knowledge are indeed so inextricably linked, authorial voice must be taught to new members of the field, the students, to become functional members of their discourse. Thus, training in both the use and understanding of discoursal writing conventions is required to develop students into successful chemists.

Teaching writing conventions in chemistry necessitates an understanding of the chemistry discourse and its corresponding rhetoric and culture that has been mentioned throughout this paper. Professional scientific discourse is defined in the literature as "a communal setting of scientists with a specific scientific domain and paradigm to find the most plausible explanation of phenomena in the world" (Hanauer, 2006, p. 189). This definition of the professional scientific discourse is arguably even narrower than "the sciences" in general and certainly narrower than STEM in general. This definition justifies a focus on chemistry because the professional chemical discourse will be unique from the professional biology or physical discourses. Even within the field of chemistry, the individual sub-fields (for example, organic, inorganic, and physical chemistry) have their own variations on the professional chemistry discourse.

However, these science discourses do hold fundamental characteristics in common. One commonality is that these discourses are all deeply rhetorical. The science discourses use many rhetorical strategies, including scientific authorial voice, that contribute to the authors' goals (Hanauer, 2006). Additionally, professional science discourses exist within communities and are constructed by those communities. The very nature of a discourse involves communication among individuals; a discourse is not possible without a community of some sort. This community does not need to refer to friendships or relational intimacy among scientists; many scientists work alone and notoriously struggle with community and relationships. In a professional academic discourse, the relationships among scientists who interact with each other's papers and yet never meet comprise the core element of the discoursal community, creating and developing the "rules" of scientific discourse developed over time as the community's needs evolve.

Membership in the scientific discourse is, therefore, just as intimately tied to one's scientific authorial voice and scientific writing skill as it is to one's content knowledge, and the ability to wield one's authorial voice well increases as one's content knowledge develops (Khuder, 2021). In other words, writing to learn and learning to write depend on one another for the development of both. The skills required to write well in the science discourse will also promote students' ability to pursue scientific inquiry at a higher standard (Cope et al., 2013; Khuder, 2021). As students' authorial voice and content knowledge increase alongside each other, so does their membership in their academic community and its discourse.

French (2019) makes this same connection between students' writing practices and their membership in their academic community but takes the connection one step further to bring the development of a "positive academic/professional identity" (p. 1615) into the picture. The connection of these three elements indicates that authorial voice in chemistry (a writing practice) is inextricably linked to both entry into the discourse and the development of personal and authorial identity within that discourse that linguistic theory describes (French, 2019). New chemists must wait until they have mastered the genre and voice of their field to be considered "real scientists." In other words, their identity as scientists, which allows them to enter the discourse, depends on their ability to use an authorial voice that follows the conventions of that discourse. Significantly, this development does not happen by accident. Instead, a conscious awareness of an academic community is required to develop a positive academic/professional identity within that community via a mature authorial voice. The development of this mature authorial voice can be expedited by providing students with critical and theoretical instruction on the details of the discoursal conventions they are stepping into via their authorial voice.

The key theme in this discussion of the connections between authorial voice, content knowledge, community membership, and identity in the context of the sciences is that *both* content knowledge *and* authorial voice are required to develop students as productive members of the discourse. A common theme in the literature identified in this study, however, was that authorial voice as a component of this development is largely absent in undergraduate chemistry instruction. The literature described science writing instruction as comprised of three components: the rhetorical component, focused on argumentation and supporting claims with evidence; the content component; and the voice component, concentrated on how tone works with argument to create a position. In most papers discussing undergraduate science education, the authors described that rhetorical and content components of science writing are primarily taught in these courses, so much so that voice components are entirely excluded. In many science writing studies, authorial voice is not even mentioned.

Of course, the other components of writing instruction are necessary and should be included in any instruction if it is to be effective. Rhetorical arguments, organization, grammar, and content are all integral to excellent writing. However, authorial voice is also essential, particularly in fields like chemistry, where membership in the community is highly valued. Undergraduate chemistry courses seem to be missing instruction on this indispensable component of scholarly development, and this lack severely limits the wholistic development of students as dynamic members of the chemistry discourse.

One solution to this problem would be simply including authorial voice instruction. The author of this paper affirms this solution as a step in the right direction, but a more foundational revision of how content knowledge is taught in conjunction with writing instruction might prove more effective. The common assumption in undergraduate chemistry departments, described

across the literature, is that students are expected to collect knowledge and skills related to writing in their field over time without direct or intentional instruction. While this method is possible, it is ineffective in the short term and induces much frustration in both students and instructors. Education at the undergraduate level has a unique opportunity to provide students with tangible preparation for learning how to interact with their new discourse and for connecting their course work to the actual operations of a scientist (Falconer, 2018), but taking advantage of this opportunity will require a fundamental shift in assumptions about effective instruction in both writing and content.

An example of what this shift in assumptions will mean for writing and content instruction is the type of assessments utilized in the sciences. The sciences typically use discrete-item assessments, such as multiple-choice tests, to assess student knowledge and progress. However, many of the skills most valued in the sciences are not tested or developed in these assessments (Cope et al., 2013). Critical thinking, problem-solving, complex conclusions, social knowledge-building, originality, reasoning based on evidence, and connections between knowledge and its social and academic contexts, all integral to the core values of the sciences, are difficult to assess via these sorts of assessments. However, these are "precisely the epistemic qualities that assessment of scientific writing is designed to measure" (Cope et al., 2013, p. 426). A shift toward assessment of writing in addition to discrete-item assessment would provide a way to assess these essential qualities more wholistically. Assessing science writing along with – not instead of – discrete-item assessment would broaden the range of skills that could be assessed in science courses and allow students to practice skills immediately useful to them as they step into the discourse.

A potential shift away from the exclusive use of discrete-item assessment would necessarily be accompanied by a shift away from teaching lists of rules related to writing and toward teaching how to evaluate appropriateness based on a given situation. An example is the APA style manual, used in many lower-level science courses and most similar to the scientific styles used. This manual was initially developed to assist writers in communicating with a particular voice. Now, most undergraduate students only associate APA with a list of rules about how to cite sources and format a title page (Ciarocco & Strohmetz, 2022). Even APA scholars who exist solely in psychology have identified this trend of teaching the formatting rules without the voice those rules are intended to accommodate. Though untested in the sciences, this trend would undoubtedly be exacerbated there. This example demonstrates that teaching and evaluation of scientific writing must be intentionally designed to avoid the tendency of scientists to discuss rules to the exclusion of softer skills such as authorial voice.

Because of the field's emphasis on memorization, instructors and students alike will find that approaching writing comes more naturally through the lens of a list of rules to memorize. However, as Devlin (2016) explains, teaching writing (and authorial voice especially) is more about teaching precision, clarity, conciseness, cohesiveness, elegance, and simplicity than grammar rules. Khuder (2021) agrees with this, explaining that the goal of teaching authorial voice should never be to fit students into a mold. Instead, the goal should be to increase their understanding of the topic and how to communicate it. Because of the emphasis on rote memorization in the sciences, this will prove a difficult shift for science instructors and students to make.

While teaching writing in this way is not easy for scientists because of the culture of the community, these values are remarkably similar to those that underlie the sciences at their core.

Real science is found in reasoning through propositions that do not appear to line up (Norris, 1995). Even content knowledge in the sciences is best taught not as a list of unalterable facts but as a list of proposed solutions to observations that did not align and as training students to propose their own solutions to similar pesky observations. When these elements of "real science" are combined with opportunities to write and instruction on community norms of authorial voice, students are equipped to develop their own discoursal identity in the chemistry community. Only when students are thus equipped can they legitimately contribute to their field, so scientific authorial voice instruction must be included alongside content instruction in undergraduate chemistry courses.

Social and Process-Related Elements of Writing

The literature also emphasized two elements of writing that are particularly profitable to writing instruction for science students: social and process-related elements. We will address the social component first, which requires a return to the circle analogy discussed in Chapter 2: authors are continually drawn both outward by their own identity and individuality and inward by the social norms of the groups of which they are a member (Schmit, 2022). The significant impact of this social pull indicates that there is a fundamental social component to learning to write in any community, even in the chemistry field.

Learning scientific authorial voice is often best accomplished via collaboration between content and writing instructors, among students, and between students and faculty from both the content area and the composition field, as well as via assistance from the writing center to all of these parties (Tatzl et al., 2012). Such collaboration requires that students be given much practice engaging, familiarizing themselves with, and practicing writing in the chemistry discourse. Additionally, instructors must practice engaging in the discourse in a more tangible way than

they might perhaps be used to. Education like this is by nature dialogic, allowing students to bring their own scientific authorial voice to the table and meld it with the authorial voice of the discipline.

The connection between scientific authorial voice and the scientific discourse is clear; Hanauer (2006) takes this association further to demonstrate that the scientific discourse is connected to social practice. This interpretation is based on the premise that discoursal writing, even science writing, is the product of a community rather than an individual or even a group of individuals. As Cope et al. (2013) propose, "Scientific literacy [understanding and interacting with scientific knowledge] is the stuff of accumulated, collective, distributed and essentially human intelligence" (p. 424). These social and collective elements of the discourse form the foundation of meaning creation and representation in academic discourse and especially in scientific discourse. Meaning creation, even in the sciences, is inherently social, based in and born out of the scientific community. Thus, even scientific authorial voice is inherently social because authors must discover who they are in the context of their community to make choices regarding how they present themselves.

Learning to understand and interact with this social scientific discourse can be tricky, especially because students approach it with their unique backgrounds. Discourses do not exist in isolation; nowhere is this more evident than when students are learning a new discourse and its practices. Sperling and Appleman (2011) emphasize that "teaching voice…means that we understand *with* students how and whether one discourse infiltrates and meshes with another, and to what rhetorical, academic, and, not least, political ends" (p. 81, emphasis theirs). As instructors interact alongside students, they build up the students' "sociolinguistic competence" (Sperling & Appleman, 2011, p. 81): their ability to know how to engage with a discourse as a

community via written conventions such as scientific authorial voice. Sociolinguistic competence includes the mediation of interactions between the chemistry discourse that is new to students and the discourses that students have previously engaged with. Here, as elsewhere, learning sociolinguistic competence as the effective expression of scientific knowledge via discoursal conventions and authorial voice is a communal task in any discourse (Norris, 1995).

Instructors and experienced chemists alike must make the communal aspect of learning chemistry writing and appropriate authorial voice very clear to undergraduate students. When students assume that their development of sociolinguistic competence happens over time and by accident, they are led to think that the problem lies with them when they encounter difficulties. When students internalize this implication (Falconer, 2018), generations of chemists can lose their enthusiasm to continue. To combat this, instructors can explicitly and implicitly teach students their appropriate role in their discourse as "young, emerging scientist[s] with much to learn, and much to offer" (Falconer, 2018, p. 29). Instructors can treat students as if they belong in the discourse and chemistry community and as if they deserve to engage in the discourse by adapting their previous knowledge and discoursal skills to the new setting. Without understanding the chemistry discourse as a social skill, this role of students is not possible, and students have little option but to be prone to isolation and discouragement.

An added benefit of teaching writing as a social skill is that it prevents writing and discourse from becoming insular (Reave, 2004). Writing in the context of a larger community ensures that students genuinely understand the content and are working to communicate it rather than simply regurgitating information in ways that might sound sophisticated to members of the same field. Social practice tied to writing practice allows students to ask questions about their writing and to consider its impact, forcing them to consider the content more carefully and craft

their writing to cater to a larger audience than their professor alone or even a limited body of experts in their field.

In addition to the social element of writing, instruction on the process-related components of writing is integral to the development of chemistry students as productive members of the discourse. This relationship is so intrinsic that it can almost be assumed to be implicit – almost. Notice that throughout this paper the *development* of students and their scientific authorial voice has been referred to. This development references the process-related elements of writing and is ubiquitous in discussions of writing instruction in any field. Despite this, the science community seems to imply that the development of writing over time will occur without intervention and that the only stage of this development worth discussing is the point at which students become members of the discourse as "real scientists." This limited perspective can lead to intense discouragement and decreased self-efficacy as students internalize the belief that they are doing something wrong if they are not immediately ready to enter the chemistry discourse.

Thus, students must be taught that development happens over time and that their lack of qualification for entering a discourse that they have not been equipped for is normal and not indicative of a fault of theirs (Falconer, 2018). Students must be taught to expect that it will take time for them to gain the writing and authorial voice skills required to enter the discourse; this evolution of skill and identity is normal and even positive. Students must learn how to comprehend what they are learning, how to "make sense" of it (Duggan, 2022), how to alternate between their own authorial voice and ideas and the voices and ideas of others, and how to achieve that balance within the standards of their discourse. Learning these skills takes time, practice, and interaction with others both in the discourse and outside of it (Sperling & Appleman, 2011). However, the development of these skills can and should be supported by

instruction so that students are not left feeling stranded, helpless, or worse, undeserving of a chance to enter the discourse.

To return to the circle analogy presented by Schmit (2022), learning to appropriately balance the pull inward toward convention with the pull outward toward creativity in both one's field and one's self seems to be a lifelong process. The lack of instruction emphasizing that learning this balance is a process leads students to believe that achieving these skills should be immediate. Students' frustration when this proves inaccurate highlights that balancing elements of discoursal conventions in learning scientific authorial voice is a process rather than a momentary achievement. Teaching students how to navigate this process and interact with others in the chemistry discourse during that process is just as important as teaching the rules of the social community's conventions.

Strategies for Explicit Instruction

Finally, while this paper is not designed to recommend specific strategies that go into explicit instruction, they deserve mention because of the amount of space devoted to them in the literature. Strategies mentioned in the literature include team teaching (Drew et al., 2020; Reave, 2004), co-planning tools, workshops (Drew et al., 2020), combining existing projects with field-specific writing assignments, group projects, integration of writing and other projects in class time, teaching a focus on the audience (Tatzl et al., 2012), multiple peer reviews (Cope et al., 2013), templates (Cope et al., 2013; Tatzl et al., 2012), utilization of online resources (Hirst, 2013), demonstration/modeling, making reasoning explicit (Cope et al., 2013; Falconer, 2018), communication modules, inclusion of instruction on international science communication, tutors, writing centers, technical writing courses, communication across the curriculum programs, content-specific writing centers (Reave, 2004), discussions of jargon, and interactions with

student voices (Hinchclilffe, 2012). All of these strategies can be used in various combinations to teach the scientific authorial voice and scientific writing in general in undergraduate chemistry courses.

Instruction using any of these strategies should emphasize the elements of general academic and scientific authorial voice described in Chapter 2, as well as the details of genre and type of writing (including lab reports, published articles, research proposals, etc.) and the purposes of scientific writing, among other topics. While the strategies mentioned in the literature and the content suggestions that go along with them are incredibly varied, the emphases of these strategies were very similar. Rather than devoting the rest of this chapter to discussing individual strategies, this section will describe the commonalities between the strategies' values and emphases to identify some elements that contribute to successful explicit instruction. These elements could be effectively utilized by the undergraduate chemistry instructor who wishes to begin instructing students in scientific authorial voice.

One such value shared among the strategies mentioned above is collaboration. This value should not be surprising when considering the social components of scientific authorial voice and the scientific discourse discussed in the previous section. The type of collaboration most often addressed in the literature is teamwork between content area instructors and writing/composition instructors. This type of collaboration can be particularly beneficial because content area instructors frequently lack explicit knowledge regarding the conventions of their discoursal communication but do possess knowledge of the authorial voice conventions of their discourse (Reave, 2004). Many of the strategies mentioned above rely on content area and writing collaboration.

The literature also repeatedly mentions a connection between increasing student motivation by teaching with a mind to relevance and context. Relevance itself is related to the meaningfulness of an assignment and whether students consider it to be relevant to them and their future. The connection between relevance as meaningfulness and student motivation seems to be direct; if students see an assignment as meaningful, they are more likely to be motivated. One way to increase relevance is by communicating the actual purpose of an assignment to students rather than providing them with an assignment devoid of context or purpose (Drew et al., 2020). By connecting writing to its context and purpose, instructors can increase student motivation to complete the project and reap its learning benefits (Tatzl et al., 2012). Putting writing in context also creates a more realistic audience for students to write to, allowing them to write based on their interests and in a setting that matters to them rather than in the somewhat sterile academic setting with only the instructor as the audience. Regardless of the strategy chosen to instruct students in scientific authorial voice, increasing relevance is central to increasing student motivation to complete and learn from instruction and assignments. Increased relevance is integral to effective instruction on authorial voice for this reason.

The brief mention in the previous paragraph of the instructor as audience brings us to the next element of the strategies identified in this review. Identifying an audience in academic writing can prove challenging for students. Practically, the audience of academic writing is usually the instructor and the instructor alone. However, this audience does not reflect the sort of audience for whom students are training to write. Effective instruction on scientific authorial voice must create a simulated environment in which students imagine their audience and the context in which they are writing to align more closely with the discourse they are training to enter. Learning to write with clarity in any field necessitates this, and chemistry students are

rarely taught to consider their audience as other than the instructor (Tatzl et al., 2012). Instructors must work with students to set the scene for their writing by establishing what the audience would know, what content might necessitate further description, and the necessary level of detail to be included. Many elements of authorial voice depend on the audience; by engaging students in a discussion of their simulated audience, instructors open a dialogue on why choices of scientific authorial voice are made in the chemistry discourse. A discussion of audience can also raise the relevance of an assignment by putting it into a more complete context.

Another fundamental component of successful explicit instruction strategies described in the literature is learning while doing. This value applies both to learning about writing and learning about content. Tatzl et al. (2012) emphasize that most writing skill development originates in practice. Specifically, the practice that formed writing skills in their study was related not to the in-class writing exercises or the regular progress reports but rather was connected to writing assignments that placed students in the role of a member of their discourse and offered them practice in that role. Learning while doing described in this way is related to both increasing relevance and discussing audience, as mentioned above.

The key in this sort of writing instruction and practice is that instructors must give feedback on the communication elements of the writing and not just its content. Content area instructors tend to grade writing solely based on its content, with some focus on rhetorical considerations related to logic and argumentation. When students discover this, they accurately deduce that any effort they put forth to improve their scientific authorial voice in a writing assignment will not be reflected in their grade. When writing instruction is taught with this structure, any writing skills gained in the project are purely incidental. Explicit instruction of scientific authorial voice requires that instructors provide feedback on and grade written

elements of communication and authorial voice in addition to content elements. Doing this gives students benchmarks by which to improve. It also teaches students that their instructors value their ability to communicate well in the discourse rather than their ability to simply regurgitate facts in essay form.

Tatzl et al. (2012) warn against the alienation of the project from the classroom in using any of the teaching strategies mentioned in the literature. Although students may learn a significant amount about writing in their discourse from a particular writing assignment, they cannot often marry that knowledge to the course itself. This disconnect is especially true in courses and fields that rely heavily on project-based learning and would primarily apply to upper-level chemistry courses in the discipline of focus for this paper.

Much of the literature identified in this study is related to mentorship experiences in undergraduate and graduate settings. While this topic is broad enough in scope to merit its own integrative review, some elements of the nature of mentorship are related to the development of scientific authorial voice and thus deserve mention here. The overwhelming opinion of the literature on mentorship is that students need experienced author-scholars to give feedback rather than simply providing corrections as they develop their authorial voice. In other words, students need their mentors to explain to them the elements of authorial voice that they are struggling with instead of simply marking some words out and adding others in. As Khuder (2021) explains, “The act of explaining the aim of metadiscourse features [elements of authorial voice] seemed important for writers to internalize their use” (p. 251). In other words, explanation rather than simple correction must be the goal if students are going to internalize their learning about the discourse and improve their scientific authorial voice over time. This explanation has been demonstrated to work most effectively when full professors act as mentors because these

instructors have more experience and less pressure to achieve and produce their own work to sustain their careers (Anderson et al., 2020). While this structure may be feasible at the graduate level (and is primarily described in a graduate context in the literature), instructors at the undergraduate level do not have the capacity to mentor every one of their students. Instead, undergraduate instructors must lean on other methods of mentorship for their students. These alternative methods can include partnerships with writing centers, peer mentoring programs, content area composition courses, etc. Peer reviews have been demonstrated to be highly effective means of evaluation and revision due to their peer mentorship element (Cope et al., 2013) that mirrors the academic peer review process and brings students into the discourse in a community setting.

Regardless of the type of mentoring developed at a given school, successful mentoring has been associated with mentor-mentee meetings that are less spontaneous and more intentional (Anderson et al., 2020). Success and even the functional details of a mentorship relationship depend on the mentor and the mentee and rely on traits such as responsibility, initial skills, and others. To move toward standardizing mentoring relationships and promoting their success, some universities and individuals use a sort of rubric to structure peer reviews (Cope et al., 2013). This strategy clarifies communication between the author and the mentor/reviewer and helps students make informed and evolving choices regarding their scientific authorial voice as they write. Such a rubric allows the author to analyze their own writing based on the comments of another. It also encourages the mentor/reviewer to practice investigating the writing of another for essential details of scientific authorial voice. A tool like this develops the skills of both the mentor and the mentee and is thus ideally suited for peer reviews among undergraduate students. This rubric could also be implemented in other mentorship relationships to make the goals of the learning

relationship more explicit. While the burden on the instructor is made much lighter via peer reviews and the associated rubrics, instructors should not be entirely disengaged from the review process. Instructors should work with students in the review process to guide them toward essential elements of scientific authorial voice. This collaboration can take place in a class setting, in a workshop setting, during office hours, or in meetings where the instructor meets with the students Involved In the review.

Most centrally, any writing instruction strategy must include a focus on self-awareness. As Cope et al. (2013) describe, “Scientific discourse…requires learners to monitor their own thinking, always self-questioning veracity and identifying possible fallacies in the meanings or the sense being made” (p. 423). To write at all, the science student must be critically aware of what they are writing, what it means, and where it might be flawed. Explicit instruction on any writing element must include instruction related to developing this awareness.

Falconer (2018) further describes this goal, saying that instructors should “consciously [draw] attention to the specific discourses conventions of a discipline” to help students “see the relationship between the aims and purposes of the disciplinary genres and the actual writing of the documents” (p. 34). Self-awareness in chemistry writing, therefore, is intimately tied to the chemistry discourse. Chemistry authors must be sensitive to the discourse, its forms and genres, and their own writing to most effectively wield these elements toward the goal they seek.

Self-awareness is therefore integral in all of the strategies described here, in instruction on the social and process-related elements of learning scientific authorial voice described in the previous section, and in the instruction of scientific authorial voice alongside content area instruction. The literature identified in this study demonstrated that as instructors and students seek self-awareness in these three thematic categories, instruction on scientific authorial voice

can flourish, and students can be developed as more enthusiastic members of the chemistry discourse.

Chapter Summary

This chapter discussed the results of the integrative review that this research performed. Themes identified in the literature fell into three key takeaways. First, explicit instruction on scientific authorial voice must exist in tandem with content instruction in undergraduate chemistry courses. Additionally, the social and process-related components of teaching scientific voice are perhaps more significant than those involving instruction such as lecturing. Finally, strategies mentioned in the literature shared key values, such as collaboration and self-awareness, that were discussed in detail in this chapter. Taken together, these three themes make a powerful argument for the use of explicit instruction to teach scientific authorial voice in undergraduate chemistry courses.

Chapter 5: Discussion

This chapter will discuss the results described in the previous chapter regarding the implications of those results for instructors and how the results might best be applied in classrooms and in future research. The results demonstrate that incorporating explicit instruction on scientific authorial voice in undergraduate chemistry classes will benefit undergraduate chemistry students by more thoroughly preparing them to enter the chemistry discourse in their graduate courses and professional careers. Instruction on scientific authorial voice is integral to undergraduate chemistry education. It must be taught alongside content knowledge and lean heavily on the social and process-related elements of writing and learning. Strategies and guiding principles for incorporating explicit instruction in the undergraduate chemistry classroom were also identified in the literature.

Potential Challenges in the Incorporation of Explicit Instruction

The results of this study indicate that explicit instruction may be an advantageous strategy for teaching scientific authorial voice to undergraduate chemistry students, but putting this solution into practice is likely to be a challenging process. Students come from many cultures and bring unique discursive identities with them to chemistry, a field with a very rigid discursive identity. Norris (1995), Sperling, and Appleman (2011) use the term sociolinguistic competence to describe the skills, social and otherwise, needed to navigate this delicate new collision of discourses. Navigating students' negotiation of their sociolinguistic competence in the chemistry discourse is a challenge that instructors and students alike struggle with.

The culturally accepted teaching methods of the sciences make teaching discoursal interactions and writing as a process particularly arduous to adopt. Teaching students how to balance their own authorial voices with the authorial voice required by their discourse is onerous because it requires instructors to shift away from the comfortable realm of memorization,

definitions, and formulas. Teaching authorial voice as a balance between the opposite pulls toward the center of the circle and toward the edge of the circle (Schmit, 2022) requires instructors to adopt a process-oriented mindset that feels more abstract than they are perhaps comfortable with. While this shift may seem simple in this brief description, these changes in teaching topics and methods are in fact dramatic. The changes in instructors' and students' ways of thinking required by this shift will prove to be almost unthinkable to most instructors and students in the chemistry discourse. Embarking with the goal of this fundamental shift in practice and mindset is an audacious calling for a chemistry instructor.

Commonly encountered prejudices against discussing writing in STEM content classrooms are related to the sheer difficulty of this ideological and practical shift. STEM students and instructors both tend to avoid writing in STEM courses due to the stigma against writing. This stigma endures despite the demonstrated value of writing as a component of content-area learning. Writing associates STEM students and instructors with less well-respected fields in their academic social settings and the context of their discourse. Uprooting this stigma may prove the biggest hurdle for implementing explicit instruction in undergraduate chemistry classrooms, and doing so will require a level of humility rarely seen in academia from both students and instructors in these classrooms.

The intention of the suggestions in this research is not to load more onto the already overburdened chemistry instructor. The emphasis of this chapter up to this point has been on the difficulties of implementing this research for instructors; this emphasis has not been made without a keen awareness of the preexisting difficulty of their role as content-area instructors. However, the problem identified by this research is significant enough that finding a solution is a requirement. Finding and implementing this solution may require the reallocation of some time

on the part of instructors. Ideas for sustainable reallocation and support for instructors are discussed later in this chapter.

In addition to being overburdened, chemistry instructors are often not prepared to teach writing and scientific authorial voice in their courses. This lack of preparedness creates another hurdle for the implementation of explicit instruction in undergraduate chemistry classrooms. STEM instructors often lack confidence in providing writing instruction because their own writing skills were intentionally and consciously developed when they were first entering the discourse (Drew et al., 2020; Whitehead, 2002). At this point, these instructors are already members of the discourse and have developed their discoursal writing skills over time; their lack of confidence and preparedness has nothing to do with their scientific writing skills, which are often quite good. However, instructors likely developed these skills subconsciously, as their training to enter the discourse likely mirrored that of the students they are teaching in its lack of clarity and emphasis. Many instructors will find that consciously teaching unconsciously obtained skills proves more difficult than expected. The lack of explicit knowledge of writing skills within the discipline and the lack of confidence in teaching a topic that is only partly within their area of expertise creates a perfect storm in which instructors often opt to avoid teaching writing and authorial voice to their students at all rather than overcome these internal barriers. This cycle has been repeating itself to create a generational pattern of avoiding writing instruction in chemistry courses that resists changes such as those proposed by this research.

Overcoming Potential Challenges

The hurdles described above mainly have to do with stigmas from scientific academic culture as well as the generational lack of preparedness of instructors to teach writing explicitly. While challenging in practice to overcome, both root issues can be resolved with intentionality

and effort. Any solution must begin with an awareness of disparate discourses and an awareness that chemistry students and instructors are operating within a particularly unique discourse. This awareness is important for both students and instructors. To develop this discoursal awareness, instructors and students alike must combine empathy with academics and learn how to interact with rhetoric and culture as they consider the place of the scientific text (Dorpenyo, 2015).

For students in particular, writing and authorial voice must be taught with an awareness of how students might bring their own "discursive identities" from their culture and previous education into the chemistry discourse they seek to join (Hyland, 2002, p. 1111). This awareness can be taught primarily in the form of open conversation. As discussions proceed regarding scientific authorial voice, instructors can take the opportunity to discuss why students make authorial voice choices that do not align with the chemistry discourse and how those choices might reflect the other discourses that they are bringing to the table. Teaching students that writing is situation-specific and that there are straightforward ways to think through situation-specific choices is key to maintaining their motivation. Instructors who do not do this risk their students knowing their writing is wrong for the discourse without being able to resolve the discrepancies. Awareness of old and new discourses is crucial for instructing students as they enter the chemistry discourse.

However, these solutions for students' hurdles of discourse awareness can only be effectively put into practice if instructors first overcome their own hurdles. Training instructors is the key to implementing explicit instruction in this context because content instructors often struggle with the explicit details of communication but know intuitively the sound of their field's discourse (Reave, 2004). In other words, instructors may not be able to explain why a certain phrase or structure is not appropriate for the chemistry discourse, but they may be able to express

when that inappropriateness shows up and how to resolve it. Thus, training chemistry instructors in the vocabulary they need to teach the specifics of writing and authorial voice in their field on a conscious level is integral to the success of explicit instruction of scientific authorial voice. Instructor training does not need to be comprehensive, although this might be warranted in some settings. In most, however, an overview may be enough to push instructors toward a conscious awareness of their own writing and why they make the choices they do in their own authorial voice.

As heavily emphasized in Chapter 4, training for instructors must utilize collaboration and community as a primary element. Learning in community as a facet of entering a new discourse was described in Chapter 4 in the context of chemistry students entering the chemistry discourse. Similarly, chemistry instructors must be trained in community to join the discourse of writing and authorial voice. Collaboration is integral here in the same way that it was demonstrated to be for teaching scientific authorial voice to students. Collaboration in the training of instructors can take the form of multiple chemistry instructors working together, chemistry instructors working with composition or writing instructors, or chemistry instructors working with writing centers or writing across the curriculum programs (Tatzl et al., 2012). The nature of this community is less important than the fact that it exists.

Some instructors have used co-planning tools to work together to create lesson plans efficiently (Drew et al., 2020). These tools can be as intricate or simple as the instructors want them to be; they are tools, not rules, and should, therefore, serve the needs of those using them. The purpose of a tool like this is to give instructors confidence, direction, and efficiency. Online platforms make the use of these tools quite simple, allowing for the simultaneous collaboration

of instructors on the same page or document. These tools can increase collaboration among instructors without overwhelming instructors by adding tasks to their to-do lists.

While these tools can be extremely productive, programs and environments that allow for physical presence and face-to-face interactions among instructors are even more powerful. For example, workshops can take many forms but can include more discussion and group work than direct instruction through talks and lectures might. Instead of hosting meetings for instructors where one individual lectures from the front of the room, proponents of increased and improved science writing education can host workshops that primarily include collaboration-based components. While increasing knowledge is important, the goal of these workshops and all strategies for educating professors must be to improve community and collaboration first and knowledge second. Regardless of the topic or activity of the workshop, the goal must always be to increase conversation and collaboration among instructors.

Some authors have described implementing comprehensive faculty development programs to accomplish this task in an organized way (Gallagher et al., 2020; Zemliansky & Berry, 2017). Programs such as these are, of course, the end goal of developing authorial voice and writing instruction in content-area fields like chemistry, but these programs may prove too ambitious for universities that are only just beginning to equip instructors toward teaching writing and authorial voice in chemistry courses. Furthermore, describing these programs as the only functional solution will likely discourage individual instructors who wish to implement explicit instruction and other classroom strategies but lack the institutional support that faculty development programs provide. Thus, while these programs can be beneficial, they are by no means necessary for the successful education of instructors in explicit instruction of authorial voice in chemistry courses. Smaller-scale efforts may prove just as successful, if not more.

Additionally, faculty development programs do not need to happen solely at the institutional level for effectiveness. A chemistry department may choose to develop a similar program among faculty members and instructors, or a writing center or composition department may create a similar program to educate content-area instructors in writing topics. External organizations could also work with departments or institutions to create opportunities for instructor training. Whatever the scale, faculty development programs are only as effective as the community they create, and the knowledge-building must be done through collaboration among instructors. Whether workshops, faculty development programs, or other methods of gathering faculty are used, these methods should all be designed to foster an environment where instructors can, in community, examine themselves and their motivations for grading, assigning, and teaching according to their current conventions (McGann, 1997).

Explaining these hurdles and their potential resolutions puts a finer point on the findings of this research. Explicit instruction on scientific authorial voice in the context of content learning is needed to develop successful scientists in undergraduate chemistry degrees. This need is so significant that solving it via explicit instruction is worth navigating a labyrinth of hurdles and finding creative solutions to those barriers.

Implications

. This study represents a significant step toward pragmatically furthering the primary goal of science education: to effectively train students to enter the science field in a professional capacity. In furthering this goal, this research laid the groundwork for future research that may facilitate the development of programs that better prepare undergraduate chemistry students for their graduate and professional lives. This foundational study and research that builds on it will primarily impact undergraduate chemistry instructors who face the lack of science writing

instruction daily and are the front line in finding a solution. Of course, an institution-wide writing across the curriculums program would be the ideal solution, but this will prove rather too ambitious for practicality in most situations.

Instead, undergraduate chemistry instructors can implement the findings of this research by beginning to integrate explicit instruction on scientific authorial voice in their own courses. Myriad resources exist in the literature and from institutions with more large-scale programs; instructors can utilize these online resources as they take the bold leap into teaching their chemistry students how to write like the well-rounded chemists they ought to be. As this integration becomes stable in one instructor's course, chemistry instructors could expand their efforts toward partnerships and team teaching. These collaborations could begin within a chemistry department as chemistry instructors work together to create teaching methods for teaching authorial voice in their own courses. Collaborations could also start with a partnership between a chemistry instructor and a writing center or composition instructor. In this case, both parties would work together to expose chemistry students to composition training and develop strategies for incorporating such training in chemistry courses. As these partnerships develop, they would expand to include team teaching where applicable. As partnerships grow, they would likely result in the development of more wholistic faculty development and writing across the curriculum programs that support the graduation of students with a robust portfolio of chemistry writing crafted throughout their undergraduate career.

Undergraduate chemistry instructors must begin this process with self-awareness. Instructors must consider the rhetorical goals of the writing they teach and whether those goals align with the rhetorical goals of the discourse in which their students are writing. They must consider their own writing and teaching practices and evaluate how well students are prepared to

enter the chemistry discourse by these practices. The conscientious chemistry instructor will humbly seek ways to improve themselves in this area, start from where they are, and incorporate explicit instruction to the best of their ability given their environment, supports, and knowledge.

The implications are the same for writing or composition instructors and writing center directors. These institutional community members must also enter the conversation with humility that produces curiosity rather than authority. These individuals must seek to learn a new discourse, not to impose their own discourse and conventions on the chemists they work with. They must remember that even though chemists often cannot clearly express their discoursal conventions, these conventions are some of the most rigorous in academia and must be firmly adhered to by members of this discourse. Accomplishing this humility and awareness requires adaptability and creativity. Composition instructors must be willing to mold their characteristic instruction methods to a form that will benefit the undergraduate chemistry environment because this environment is not conducive to many of those methods as they are typically used in composition settings.

Practically, writing instructors as well as chemistry instructors must engage in as many opportunities for writing across the curriculum as possible. These include, but are not limited to, trainings, workshops, conversations, and tutoring. Instructors should strive to expose themselves to different discourses, learn from instructors in those discourses, and work with these uniquely trained instructors to develop instructional methods that will work in those discourses. If all instructors approach this task with humility, determination, and a passion for developing students to the best of their ability, success will be inevitable, even if the path to that success is not as smooth as desirable.

Mitigation of Limitations

While these results and implications appropriately represent the literature on teaching scientific authorial voice in undergraduate chemistry classrooms, this study did have some limitations. The first of these is the scope of the project, which was limited due to the nature of the research as a master's-level thesis. The content addressed in this research represented a much more extensive range of applicable literature. Still, this study represents the first argument for using explicit instruction in undergraduate chemistry courses to teach scientific authorial voice. Because it lays the groundwork for future research of both types, this research functions as an initial work in its field despite its limited scope. Further research based on this study's findings should take the form of more extensive literature reviews as well as qualitative research.

Other limitations of this study were related to search terms and available literature. While listing the search terms used during the research would have improved replicability, this step was not performed when collecting data for this project. Search terms included in the methodology chapter and Appendix A were listed from memory and thus are the author's best representation of the search terms used in this study but not a strictly systematic record. These search terms, therefore, approximate those actually used in the research but are not an exact replica of them.

Additionally, this research encountered a not-unanticipated limitation in the literature, as very little literature exists that directly applies to the research questions in this study. This lack of applicable literature primarily exists because teaching scientific authorial voice in undergraduate chemistry classrooms is a new topic in both the composition and chemistry fields, indicating an area in which future research is needed. For this study, this limitation was mitigated by drawing conclusions from extrapolated findings in similar fields and studies. For example, very little research exists on instruction in writing and scientific authorial voice in any science at the undergraduate level. Most of the literature identified in this study was drawn from grade-school

or doctoral settings rather than undergraduate settings. Additionally, writing instruction in chemistry is almost nonexistent in this literature. Almost all the literature identified in this study was drawn from biology, engineering, or a combination of the hard sciences rather than chemistry at any level. This research identified these areas as those where future research is needed.

Finally, members of the audience may consider this research's affiliation with a Christian university as a limiting factor to the design of this research and the implementation of its findings. To mitigate this potential limitation, the research was conducted without mention or consideration of the worldview represented by the university or any other worldview. Because of this intentional separation of worldview and research in the design of this study, holding a particular worldview will be irrelevant to the successful implementation of the findings of this research. Regardless of worldview, this research can play an instrumental role in the discourses in which it belongs and in the decisions made by individuals within those discourses.

Future Research

The significant lack in existing research regarding teaching scientific authorial voice to undergraduate chemistry students indicates that much future research is needed. After conducting more in-depth literature reviews, the first step in this research will be qualitative empirical research, which will expand the evidence in this field. This type of research will primarily need to be composed of interviews and questionnaires of instructors, beginning with phenomenologies and ending with interventions to identify the most productive and successful strategies. Chemistry instructors must be asked about their perspectives on teaching and learning scientific authorial voice in undergraduate chemistry classrooms, their past training in scientific authorial voice and how to teach it, and their current practices and expectations in this area. Composition

instructors must also be asked about their perspectives and experiences interacting with chemists in this area. These populations' responses can be compared with the existing literature on this topic to paint a picture of the evolution of practices for teaching scientific authorial voice and how current practices might be improved.

The other significant population at play in this future research is undergraduate chemistry students and recent graduates from undergraduate chemistry programs who are in the first year of their master's, PhD, or professional career. Future research should examine how well-prepared these students feel for the field they are entering or about to enter regarding discourse, writing, and scientific authorial voice. Research should also identify specific elements of undergraduate courses that students feel prepared them well and elements that they wish had been included to improve their level of preparation.

After instructor and student perspectives have been gleaned from these research projects, these findings must be combined with research-supported instruction methods used in composition courses to develop applied research that tests the efficacy of these methods in undergraduate chemistry courses. The structure of this research should be designed most similarly to education research. Together with the perspectives gleaned from instructors and students, applied research will help design the most effective implementation of explicit instruction on scientific authorial voice in undergraduate chemistry courses.

Chapter Summary and Concluding Comments

The results of this research have implications for chemistry and composition instructors alike in terms of the application of explicit instruction methods to the teaching of scientific authorial voice in undergraduate chemistry courses. Challenges facing these instructors include students' sociolinguistic competence development, the required ideological shift in teaching

methods, and instructors' lack of time, preparation, and confidence. Overcoming these challenges requires discoursal awareness on the part of both students and instructors and training of instructors in scientific authorial voice and in its explicit instruction. Undergraduate chemistry instructors must begin to integrate explicit instruction on scientific authorial voice on a small scale; this integration will grow over time with intentionality and effort. Undergraduate chemistry instructors and composition instructors alike must cultivate humility, self-awareness, and curiosity in order to effectively implement the explicit instruction described by this research.

This research concludes that the significance of including explicit instruction on scientific authorial voice in undergraduate chemistry courses cannot be overstated in terms of its ability to maximize the production of successful chemists. Additionally, this research has laid the groundwork for further qualitative research that is needed, and warranted, to determine specific solutions and the best directions for steps toward those solutions. This future research includes qualitative empirical research to discover the experiences and perspectives of undergraduate chemistry instructors and students, as well as applied research that tests explicit instruction implementation.

Instruction in writing and scientific authorial voice are critical components of the training of successful chemists. Explicit instruction on scientific authorial voice incorporated in undergraduate chemistry courses has the potential to improve this training dramatically. Further research that builds on the findings of this research is needed to propose specific strategies of explicit instruction as solutions to the current shortcomings in the education of undergraduate chemistry students. By committing to further research in this area, undergraduate chemistry instructors and undergraduate composition instructors alike can contribute to the successful

development of chemistry students who are well-prepared for their professional and academic careers.

References

Aitchison, C., Catterall, J., Ross, P., & Burgin, S. (2012). “Tough love and tears”: Learning doctoral writing in the sciences. *Higher Education Research and Development*, *31*(4), 435–447. https://doi.org/10.1080/07294360.2011.559195

American Chemical Society. (2022). *2023 ACS Guidelines for Undergraduate Chemistry Programs: Working Draft*. American Chemical Society. https://www.acs.org/content/dam/acsorg/education/standards-guidelines/approval-program/guidelines-draft-sept2022.pdf

American Chemical Society. (2023). *Science Education Policy*. American Chemical Society. https://www.acs.org/content/dam/acsorg/policy/publicpolicies/education/educationpolicies/2023-science-education.pdf

Anderson, C., Chang, S., Lee, H., & Baldwin, C. (2020). Identifying effective mentors in science communication: A latent profile analysis of mentor beliefs. *Journal of Career Development*, *49*(2), 251–268. https://doi.org/10.1177/0894845320924127

Appleby, Y., Roberts, S., Barnes, L., & Qualter, P. (2012). Who wants to be able to do references properly and be unemployed? STEM student writing and employer needs. *Journal of Learning Development in Higher Education*. https://doi.org/10.47408/jldhe.v0i0.188

Badenhorst, C., Moloney, C., Rosales, J., Dyer, J., & Ru, L. (2015). Beyond deficit: Graduate student research-writing pedagogies. *Teaching in Higher Education*, *20*(1), 1–11. http://dx.doi.org/10.1080/13562517.2014.945160

Baker, S. (2017). Students’ writing “in transition” from A-levels to university: How assessment drives students’ understandings, practices, and discourses. *Assessment and Evaluation in Higher Education*, *42*(1), 18–36. https://doi.org/10.1080/02602938.2015.1082174

Banik, G. M., Baysinger, G., Kamat, P. V., & Pienta, N. J. (Eds.). (2020). *ACS Guide to Scholarly Communication*. American Chemical Society. 10.1021/acsguide

Banks, D. (2021). Passive voice, first person pronouns and mental process verbs in the physical sciences research article. *Revista de Linguista y Lenguas Aplicadas*, *16*(1), 37–48. https://doi.org/10.4995/rlyla.2020.14434

Cameron, C., Lee, H. Y., Anderson, C., Byars-Winston, A., Baldwin, C. D., & Chang, S. (2015). The role of scientific communication skills in trainee's intention to pursue biomedical research careers: A social cognitive analysis. *CBE - Life Sciences Education*, *14*(4). https://www.lifescied.org/doi/epdf/10.1187/cbe.14-09-0152#:~:text=https%3A//doi.org,open_in_new

Ciarocco, N. J., & Strohmetz, D. B. (2022). Teaching APA style: Missing the forest for the trees? *Scholarship of Teaching and Learning in Psychology*, *8*(4), 399–403. https://doi.org/10.1037/stl0000304

Cope, B., Kalantzis, M., Abd-El-Khalick, F., & Bagley, E. (2013). Science in writing: Learning scientific argument in principle and practice. *E-Learning and Digital Media*, *10*(4), 420–441. https://doi.org/10.2304/elea.2013.10.4.420

Devlin, K. (2016). Is the academic essay becoming a fossil through lack of authorial voice? The case for more stylish and exploratory writing. *Spark: UAL Creative Teaching and Learning Journal*, *1*(1), 34–40.

Dorpenyo, I. (2015). Mapping a space for a rhetorical-cultural analysis: A case of a scientific proposal. *Journal of Technical Writing and Communication*, *45*(3), 226–242. https://doi.org/10.1177/0047281615578845

Drew, S., Olinghouse, N., & Faggella-Luby, M. (2020). Reconceptualizing instruction for writing in science using the WiS co-planning tool. *Teaching Exceptional Children*, *52*(4), 200–221. https://doi.org/10.1177/0040059919878669

Duggan, P. (2022). Examining the influence of argument driven inquiry instructional approach on female students of color in sixth grade science: Its impact on classroom experience, interest, and self-efficacy in science, written argumentation skills, and scientific voice. *University of South Carolina ProQuest Dissertations Publishing*, 29398240. https://go.openathens.net/redirector/liberty.edu?url=https://www.proquest.com/dissertations-theses/examining-influence-argument-driven-inquiry/docview/2791345053/se-2

Dysthe, O. (2002). Professors as mediators of academic text cultures: An interview study with advisors and master's degree students in three disciplines in a Norwegian University. *Written Communication*, *19*(4), 493–544. https://doi.org/10.1177/074108802238010

Elbow, P. (2007). Voice in writing again: Embracing contraries. *College English*, *70*(2), 168–188.

Falconer, H. (2018). "I think when I speak, I don't sound like that": The influence of social positioning on rhetorical skill development in science. *Written Communication*, *36*(1), 9–37. https://doi.org/10.1177/0741088318804819

Feng, J., & Hyland, K. (2021). "The goal of this analysis...": Changing patterns of metadiscursive nouns in disciplinary writing. *Lingua*, *252*. https://doi.org/10.1016/j.lingua.2020.103017

French, A. (2019). Academic writing as identity-work in higher education: Forming a "professional writing in higher education habitus." *Studies in Higher Education*, *45*(8), 1605–1617. https://doi.org/10.1080/03075079.2019.1572735

Gallagher, J., Turnipseed, N., Yoritomo, J., Elliott, C., Cooper, S., Popovics, J., Prior, P., & Zilles, J. L. (2020). A collaborative longitudinal design for supporting writing pedagogies of STEM faculty. *Technical Communication Quarterly*, *29*(4), 411–426. https://doi.org/10.1080/10572252.2020.1713405

Goals 2000: Educate America Act, H.R.1804, 103rd Congress (1994). https://www.congress.gov/bill/103rd-congress/house-bill/1804#:~:text=Goals%202000%3A%20Educate%20America%20Act%20%2D%20Title%20I%3A%20National%20Education,and%20health%20education)%3B%20(4

Goldsmith, R., & Willey, K. (2014). *Invisible writing (practices) in the engineering curriculum?* AAEE 2014, Wellington NZ. http://dx.doi.org/10.13140/2.1.1519.3602

Goldsmith, R., Willey, K., & Boud, D. (2017). Investigating invisible writing practices in the engineering curriculum using practice architectures. *European Journal of Engineering Education*, *44*(1–2), 71–84. https://doi.org/10.1080/03043797.2017.1405241

Gourlay, L. (2009). Threshold practices: Becoming a student through academic literacies. *London Review of Education*, *7*(2), 181–192. https://doi.org/10.1080/14748460903003626

Hanauer, D. (2006). *Scientific Discourse: Multiliteracy in the Classroom*. Bloomsbury Publishing.

Harwood, N. (2009). An interview-based study of the functions of citations in academic writing across two disciplines. *Journal of Pragmatics*, *41*(3), 497–518. https://doi.org/10.1016/j.pragma.2008.06.001

Hinchclilffe, J. (2012). *Secondary Science and Nonmainstream Students: Science Teaching through De-centering Pedagogy and Practices*. 354–386.

https://archives.evergreen.edu/1989/1989-10/2012Conference/MIT2012book.pdf#page=358

Hirst, R. (2013). Improving scientific voice in the science communication center at UT Knoxville. *Journal of Technical Writing and Communication*, *43*(4), 425–435. https://doi.org/10.2190/TW.43.4.e

Humphrey, R. C., Davidson, A. J., & Walton, M. D. (2014). "I'm gonna tell you all about it": Authorial voice and conventional skills in writing assessment and educational practice. *The Journal of Educational Research*, *107*, 111–122. https://doi.org/10.1080/00220671.2013.788990

Hyland, K. (2002). Authority and invisibility: Authorial identity in academic writing. *Journal of Pragmatics*, *34*(8), 1091–1112.

Hyland, K. (2005). Stance and engagement: A model of interaction in academic discourse. *Discourse Studies*, *7*(2), 173–192. https://doi.org/10.1177/1461445605050365

Hyland, K., & Guinda, C. S. (Eds.). (2012). *Stance and Voice in Written Academic Genres*. Palgrave Macmillan UK.

Hyland, K., & Jiang, F. (2018). "In this paper we suggest": Changing patterns of disciplinary metadiscourse. *English for Specific Purposes*, *51*, 18–30. https://doi.org/10.1016/j.esp.2018.02.001

Johansen, E., & Harding, T. (2013). "So I forgot to use 1.5 line spacing! It doesn't make me a bad nurse!" The attitudes to and experiences of a group of Norwegian postgraduate nurses to academic writing. *Nurse Education in Practice*, *13*(5), 366–370. https://doi.org/10.1016/j.nepr.2012.10.001

Khuder, B. (2021). *Science in exile: EAL academic literacies developent of established Syrian academics* [Chalmers University of Technology]. 10.13140/RG.2.2.15592.6016

Kim, E. (2015). Quantitative evidence on the uses of the first person pronoun (I and We) in journal paper abstracts. *Journal of the Korean Society for Information Management*, *32*(1), 227–243. https://doi.org/10.3743/KOSIM.2015.32.1.227

Lillis, T. (2014). Academic Literacies. In *The Routledge Companion to English Studies* (1st ed.). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315852515-27/academic-literacies-theresa-lillis

Maguet, M. L., Morrison, T. G., Wilcox, B., Nixon, R. S., & Billen, M. T. (2020). Identifying elements of voice in first-grade science writing. *Reading Psychology*, *41*(8), 803–820. https://doi.org/10.1080/02702711.2020.1782292

Maloch, B., & Bomer, R. (2013). Research and policy: Informational texts and the Common Core Standards: What are we talking about, anyway? *Language Arts*, *90*(3), 205–213. https://www.jstor.org/stable/41804394

Marchant, T., Anastasi, N., & Miller, P. (2011). Reflections on academic writing and publication for doctoral students and supervisors: Reconciling authorial voice and performativity. *International Journal of Organisational Behavior*, *16*(1), 13–29. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=53a16f095a9951c15051085695b35c92bc1c9e71

Maton, K. (2016). Legitimation code theory: Building knowledge about knowledge building. In *Knowledge-building: Educational Studies in Legitimation Code Theory*. Routledge.

Matsuda, P. (2015). Identity in written discourse. *Annual Review of Applied Linguistics*, *35*, 140–159. https://doi.org/doi:10.1017/S0267190514000178

McGann, P. (1997). “Well, think again!”: Remarking on grading, subject positions, and writing pedagogy. *Composition Studies*, *25*(2), 19–31.

Mhilli, O. (2023). Authorial voice in writing: A literature review. *Social Sciences & Humanities Open*, *8*(1), 100550. https://doi.org/10.1016/j.ssaho.2023.100550

Moradi, F., & Montazeri, M. R. (2024). Voices in methodology: Analyzing self-mention markers in English and Persian psychology research articles. *Frontiers in Research Metrics and Analytics*, *9*, 1336190. https://doi.org/10.3389/frma.2024.1336190

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects*. National Governors Association Center for Best Practices, Council of Chief State School Officers. https://www.thecorestandards.org/wp-content/uploads/ELA_Standards1.pdf

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The National Academies Press.

Negretti, R., & McGrath, L. (2020). English for specific playfulness? How doctoral students in science, technology, engineering and mathematics manipulate genre. *English for Specific Purposes*, *60*, 26–39. https://www.sciencedirect.com/science/article/pii/S0889490620300211?via%3Dihub#:~:text=https%3A//doi.org/10.1016/j.esp.2020.04.004

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press.

Norris, S. P. (1995). Learning to live with scientific expertise: Toward a theory of intellectual communalism for guiding science teaching. *Science Education*, *79*(2), 201–217. https://doi.org/10.1002/sce.3730790206open_in_new

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240. https://doi.org/10.1002/sce.10066

O'Hallaron, C. L., & Schleppegrell, M. J. (2016). "Voice" in children's science arguments: Aligning assessment criteria with genre and discipline. *Assessing Writing*, *30*, 63–73. https://doi.org/10.1016/j.asw.2016.06.004

Reave, L. (2004). Technical Communication instruction in engineering schools: A survey of top-ranked U.S. and Canadian Programs. *Journal of Business and Technical Communication*, *18*(4), 452–590. https://doi.org/10.1177/1050651904267068

Riccioni, I., Bongelli, R., & Zuczkowski, A. (2021). Self-mention and uncertain communication in the British Medical Journal (1840-2007): The decrease of subjectivity uncertainty markers. *Open Linguistics*, *7*, 739–759. https://doi.org/10.1515/opli-2020-0179

Ross, P. M., Burgin, S., Aitchison, C., & Catterall, J. (2011). Research writing in the sciences: Liminal territory and high emotion. *Journal of Learning Design*, *4*(3), 14–27.

Sampson, V. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching*, *49*(9), 1122–11148. https://doi.org/10.1002/tea.21037

Schmit, J. S. (2022). *The Sociolinguistics of Written Identity: Constructing a Self*. Palgrave Macmillan.

Sperling, M., & Appleman, D. (2011). Voice in the context of literacy studies. *Reading Research Quarterly*, *46*(1), 70–84. https://doi.org/dx.doi.org/10.1598/RRQ.46.1.4

Stock, I., & Eik-Nes, N. L. (2016). Voice feature in academic texts—A review of empirical studies. *Journal of English for Academic Purposes*, *24*, 89–99. https://doi.org/10.1016/j.jeap.2015.12.006

Tatzl, D., Hassler, W., Messnarz, B., & Flur, H. (2012). Technical communication instruction in engineering schools: A survey of top-ranked U.S. and Canadian Programs. *Journal of Technical Writing and Communication*, *42*(3), 279–304. https://doi.org/10.2190/TW.42.3.f

Torraco, R. J. (2005). Writing integrative literature reviews: Guidelines and examples. *Human Resource Development Review*, *4*(3), 251–367. https://doi.org/10.1177/1534484305278283

Torraco, R. J. (2016). Writing integrative literature reviews: Using the past and present to explore the future. *Human Resource Development Review*, *15*(4), 404–428. https://doi.org/10.1177/1534484316671606

Walková, M. (2019). A three-dimensional model of personal self-mention in research papers. *English for Specific Purposes*, *53*, 60–73. https://doi.org/10.1016/j.esp.2018.09.003

Wang, Y., & Hu, G. (2023). Shell noun phrases in scientific writing: A diachronic corpus-based study on research articles in chemical engineering. *English for Specific Purposes*, *71*, 178–190. https://doi.org/10.1016/j.esp.2023.05.001

Webb, C. (1992). The use of the first person in academic writing: Objectivity, language, and gatekeeping. *Journal of Advanced Nursing*, *17*(6), 747–752. https://doi.org/10.1111/j.1365-2648.1992.tb01974.x

Whitehead, D. (2002). The academic writing experience of a group of student nurses: A phenomenological study. *Journal of Advanced Nursing*, *38*(5), 431–539. https://doi.org/10.1046/j.1365-2648.2002.02211.xopen_in_new

Yang, A., Zheng, S., & Ge, G. (2015). Epistemic modality in English-medium medical research articles: A systemic functional perspective. *English for Specific Purposes*, *38*, 1–10. https://doi.org/10.1016/j.esp.2014.10.005

Yasuda, S. (2022). Natural scientists' perceptions of authorial voice in scientific writing: The influence of disciplinary expertise on revoicing processes. *English for Specific Purposes*, *67*, 31–45. https://doi.org/10.1016/j.esp.2022.03.001

Zemliansky, P., & Berry, L. (2017). A writing-across-the-curriculum faculty development program: An experience report. *IEEE Transactions on Professional Communication*, *60*(3), 306–316. https://doi.org/10.1109/TPC.2017.2702041

Appendix A

A core element of the methodology of this research was the literature review, which was accomplished using a variety of search terms. A sample of these search terms is included below. These terms were used to find and identify relevant literature. Other literature was identified using the references of initial articles and sources, and by searching the articles and sources that have cited initial articles and sources since their date of publishing.

1. authorial register
2. authorial voice
3. authorial voice standards
4. chemistry writing
5. explicit instruction
6. instruction
7. pedagogy
8. pedagogy of science writing
9. pedagogy of scientific authorial voice
10. science writing
11. scientific authorial register
12. scientific authorial voice
13. teaching
14. teaching chemistry writing
15. teaching science writing
16. teaching scientific authorial voice
17. teaching writing
18. undergraduate chemistry

19. writing
20. writing instruction
21. writing instruction
22. writing pedagogy
23. writing standards

Appendix B

By far, the primary type of scholarly literature utilized in this research was the journal article. Journal articles were drawn from 46 unique journals ranging from journals dealing with engineering writing standards to journals discussing theories of writing and teaching writing. These journals are listed alphabetically below. Other types of sources classified as scholarly literature and utilized in this research include books and sections of books, conference papers, bills, academic theses and dissertations, and documents published by the American Chemical Society.

1. Annual Review of Applied Linguistics
2. Assessing Writing
3. Assessment and Evaluation in Higher Education
4. CBE - Life Sciences Education
5. College English
6. Composition Studies
7. Discourse Studies
8. E-Learning and Digital Media
9. English for Specific Purposes
10. European Journal of Engineering Education
11. Frontiers in Research Metrics and Analytics
12. Higher Education Research and Development
13. Human Resource Development Review
14. IEEE Transactions on Professional Communication
15. International Journal of Organisational Behavior

16. Journal of Advanced Nursing
17. Journal of Business and Technical Communication
18. Journal of Career Development
19. Journal of English for Academic Purposes
20. Journal of Learning Design
21. Journal of Learning Development in Higher Education
22. Journal of Pragmatics
23. Journal of Research in Science Teaching
24. Journal of Technical Writing and Communication
25. Journal of the Korean Society for Information Management
26. Knowledge-building: Educational Studies in Legitimation Code Theory
27. Language Arts
28. Lingua
29. London Review of Education
30. Nurse Education in Practice
31. Open Linguistics
32. Reading Psychology
33. Reading Research Quarterly
34. Revista de Linguista y Lenguas Aplicadas
35. Scholarship of Teaching and Learning in Psychology
36. Science Education
37. Social Sciences & Humanities Open
38. Spark: UAL Creative Teaching and Learning Journal

39. Studies in Higher Education
40. Teaching Exceptional Children
41. Teaching in Higher Education
42. Technical Communication Quarterly
43. The Journal of Educational Research
44. The Routledge Companion to English Studies
45. University of South Carolina ProQuest Dissertations Publishing
46. Written Communication