ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 25, NO. 1, 71-92

The Implementation of Reform-Based Standards in High School Chemistry Classrooms Influenced by Science Teaching Orientations

Michael B. Burt
Illinois State University

Sarah B. Boesdorfer
Illinois State University

ABSTRACT

Recent reform efforts have been adopted in the United States to reimagine student learning in science. Historical reform efforts have required teacher buy-in necessary for substantive change to occur. Using a mixed-method methodology, chemistry teacher progress in implementing the *Next Generation Science Standards* in Illinois and views about the purpose of science teaching and learning were explored in the context of teachers' curriculum design decisions. The results of this exploratory study suggest that standards alone are not sufficient for implementation. Chemistry teaching and learning appear to be partially mediated by a canon of knowledge that does not fully complement the standards teachers are asked to implement.

Keywords: science education, science curriculum, science instruction, educational change, teacher education, chemistry education

Introduction

Recent reform-based efforts that reimagine 21st century science teaching and learning are being adopted and implemented across the world. Since 2014, more than 20 states in the United States have adopted the *Next Generation Science Standards* (NGSS) and 24 others have developed their own standards based on the National Research Council's Framework for K-12 Education on which NGSS is also based (NSTA, n.d.). These standards are premised on the integration of content (disciplinary core ideas), scientific practice (science and engineering practices), and overarching ideas that transcend single, narrow topics (crosscutting concepts; nature of science) that are unified around real-life phenomena (NGSS Lead States, 2013a). Central to the idea behind this iteration of standards-based reform is the implementation of a model of science education that emphasizes deep connections and sensemaking over the breadth of content traditionally prioritized in curricula prior to their adoption (NRC, 2012).

The successful implementation of curricular reforms relies on several factors, but perhaps most important is the teacher buy-in that allows for transformation. Levin (2010) explains that "lasting school improvement will not come from the mindless adoption of someone else's plan or program but must involve thoughtful participation by many people within each school and community" (p. 742). In order to successfully adopt these standards, there must be a commitment to unifying reform-based approaches to teaching with a critical eye toward the role of content in secondary education. To do so requires a system of targeted professional development to develop the capacity of professionals asked to implement these standards in their classes (Banilower, 2019) and help minimize the potential for what Staw (1976) described as an "escalation of commitment" to curricular ideations of the past.

Implementing new standards requires teachers to transform their instructional approaches and contexts to reflect new expectations for student learning. As a result, it is critical to check in and examine the current status of these reform efforts in actual classrooms with practicing teachers. Pedagogical content knowledge (PCK) provides a useful framework for understanding the role that teacher decision-making and cognition play in the implementation of a standards-based reform. Using orientations to science teaching within the PCK framework to interpret results, this study explored Illinois secondary science teachers' reported implementation of a new science reform (NGSS) and its impact on enacted curriculum. Enacted curriculum in this case refers to the set of material resources as well as the content included or excluded from the cycle of learning experiences that teachers offer a given class. Core to this definition is the understanding that teachers play an active role in shaping curriculum rather than enacting that of others (Remillard, 2005). This study provides insight into the extent science teachers have adapted their practice to implement a new standards-based reform in ways that may reflect their own views. This study used chemistry teachers because of its relevance to physical science standards in NGSS and its prevalence as a core science class at the secondary level. These findings hold implications for future professional development and collaboration between secondary and tertiary science educators.

Literature Review

In this section, we make the case for why it is appropriate to study the implementation of NGSS in introductory chemistry courses in the state of Illinois and discuss some of the challenges to successful implementation of standards-based reforms.

The Link Between Chemistry Curriculum and NGSS

NGSS does not act as an explicit curriculum for discipline-specific science courses. In fact, these standards promote an integrated approach to science. Appendix K of NGSS offers model course maps for implementation of the standards, in part, based on "frequently taught courses of biology, chemistry, and physics" (NGSS Lead States, 2013b, p. 128). Nationally, introductory chemistry accounts for approximately 19% of all science courses taken at the high school level, second only to introductory biology at 29% (Smith, 2019), suggesting that, for many students, high school chemistry courses must align with NGSS if they are to meet these standards. Given that chemistry and biology account for nearly 50% of all science courses taken, it's likely that they represent the only opportunity that students will have to engage with most of the high school level physical science and life science standards, respectively.

The NRC (2012) framework for "PS1: Matter and Its Interactions" serves as the basis for much of the NGSS content that is presumed to be covered in a typical chemistry classroom. Students are expected to demonstrate proficiency based on each individual standard, known as Performance Expectations (PE), where they will explore relevant phenomena relating to broad disciplinary core ideas such as the structure and properties of matter, chemical reactions, and nuclear processes by using the science and engineering practices and crosscutting concepts. In doing so, students are able to dig deeper into concepts like the electronic structure of the atom, its characteristics and representation on the periodic table of the elements, and interactions of matter due to those properties as well as chemical reaction rates, bond energies, and the reversible nature of many chemical reactions in which matter is conserved (NGSS Lead States, 2013a; NRC, 2012). These same topics outlined in the *Next Generation Science Standards* (NGSS) are shared by the American Chemical Society (ACS) Guidelines and Recommendations for teaching middle and high school chemistry (2018). The successful implementation of these standards in a chemistry classroom would necessarily position these areas of physical science as central to student learning experiences and drive the curricular decision making of teachers. These align with the topics of this study (See Table 2).

The state of Illinois served as a sample population of teachers to explore the extent that NGSS is being implemented by adoptive states. Illinois was one of the lead states that participated in the development of these standards (NGSS Lead States, 2013a). For that reason, our study is situated in the context of Illinois as a sample that largely represents the work done throughout the United States. In the state of Illinois, there is a two-year science requirement (ISBE, 2016). As a result, many students are only exposed to science curriculum through a limited number of courses. Among high school graduates in the state of Illinois from the years of 2017-2019, no more than 20.68% had taken a course in physical science while 75.47% or more took introductory chemistry (ISBE, 2020) suggesting some NGSS must be covered in high school chemistry if students are to learn them. These physical science standards cannot reasonably be realized in a physical science course due to the limited number of students that take them; rather, they are allocated to introductory chemistry classes that are taken far more often. As a result, we will be focusing on chemistry classrooms as representative of the most common setting that Illinois students will be exposed to many of the physical science standards outlined in NGSS.

Teachers' Enactment of New Standards

The adoption of new standards represents the beginning of efforts to bring those changes to individual schools and classrooms. Central to this implementation is the work of teachers (Fullan, 2007). McLaughlin (1987) suggests that implementation begins, in earnest, once teachers are no longer concerned with the 'what' of the change, but the 'how'. In doing so, "...internal factors such as commitment, motivation, and competence dominate" (p. 174).

Often described as buy-in, the beliefs, perceptions, and values of teachers generally and in terms of the specific reform are essential in the process of implementation (Datnow et al., 2006). Transformation in teachers requires shifts in deeply-ingrained beliefs and understanding that result from personal reflection, experimentation, and cognitive restructuring which can take as long as three to five years to result in a new teaching practice to be fully implemented (Loucks-Horsley et al., 2010). There must be a fundamental change in people (the teachers) responsible for carrying out those reforms as each individual "...holds a set of assumptions that shape and are shaped by his or her values and actions" (Finnan, 2000, p. 6). Implementation of new standards operates on a similar constructivist learning paradigm that governs the very reform-based standards being explored.

Another factor relating to the implementation of reform efforts is teachers' view of students and their relation to the new instructional outcomes they are asked to achieve. Harris (2012) explains that the success of standards-based reform efforts hinges on "...unearthing deeply entrenched ideas about student deficits and intelligence" (p. 146). In addition to shaping views on pedagogy within the implementation of standards, teachers must confront the ways in which their perceptions of their students' capacity for learning shapes their choices in the classroom.

Lawrenz et al. (2005) explained how a previous standards-based reform effort was generally not sustainable due to "...external pressures, power structures [in the school] in relation to the reform, the availability of support, and the desire for change" (p. 11). Porter et al. (2014) use the context of recent Common Core reform efforts to suggest that as change efforts were increasingly perceived by teachers to be "duplicative, incorrect, or unfocused", the more likely it would be that the implementation was inadequate (p. 135). As potential agents for change, teachers have an outsized role in determining the success of a reform. The ability to engage successfully in "change" hinges on social learning and teachers' willingness to do something new, to develop "new meanings, new behaviors, new skills, and new beliefs" (Fullan, 2007, p. 97). Capturing information about the status of ongoing reform efforts requires insight into how teachers position themselves relative to the standards and whether their beliefs align with the goals of a reform effort. A teachers' pedagogical content knowledge (PCK) allows for insight into teachers' understanding and views relating to student learning.

Theoretical Framework

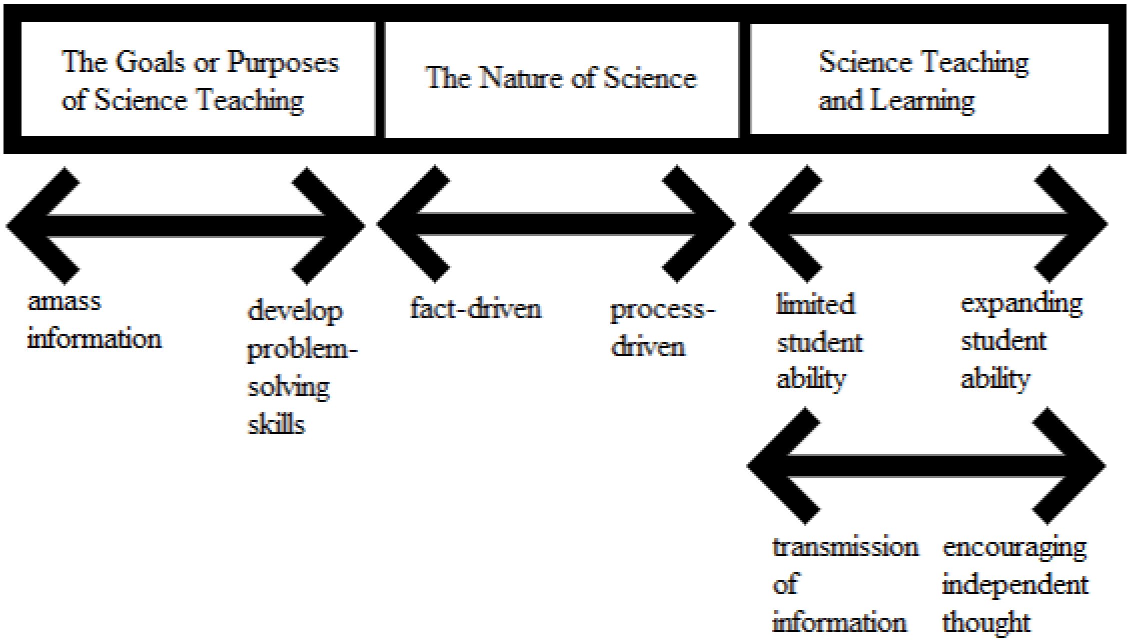
The shifts that teachers make to their personal cognitive structures as a result of efforts to begin implementing new standards in their classes can be understood in terms of their PCK. Previous studies have shown links between PCK and implementation of reform teaching standards (Wongsopawiro et al., 2016; Park et al., 2010; Cohen & Yarden, 2008). Since PCK impacts teachers' implementation of reform, we are using PCK, specifically their orientation toward science teaching, as a framework to examine their curricular choices and the way they've implemented NGSS in chemistry courses in IL.

This framework has served as a useful tool since Shulman (1986) presented a view of teacher proficiency (PCK) that represents the cognitive approaches and strategies that individual teachers use to integrate both their pedagogical and content knowledges and how they influence how students learn. In this model, teachers operationalize their content knowledge and pedagogical knowledge relating to science teaching, knowledge of curriculum, student understanding, assessment, and instructional strategies (Magnusson et al., 1999). Friedrichsen et al. (2011) elaborated on the existing model of PCK to include an explanation of an individual teacher's attitudes and beliefs relating to the teaching of science, described as their orientation towards science teaching, and described it's influence on the use of pedagogical and content knowledge in practice. Their clarification of the nature of orientations within the PCK framework suggests that teachers filter their views through lenses that relate the goals or purposes of science teaching, the nature of science, and science teaching and learning as they enact their PCK.

Friedrichsen et. al (2011) describe these orientations, in part, using a similar model offered by Lotter et al. (2007) that presents orientations along a series of continua and suggest that they each play a role in shaping the specific pedagogical and content knowledge teachers utilize in specific learning contexts. A modified view of teacher orientations using both the Friedrichsen et. al (2011) and Lotter et al. (2007) models is presented in Figure 1. These orientations effectively serve as amplifiers or mediators of student outcomes (Neuman et al., 2018). Ongoing professional development provides a necessary opportunity for teachers to reflect on and challenge their orientation(s) and actions in the classroom as they work to implement new standards and transform their practice (van Driel et al., 2001).

For this paper, we are using Figure 1 to interpret the ways in which teachers' orientations to science teaching influence curricular design and, eventually, in the enacted curriculum experienced by students.

Figure 1
Revised Model of Teacher Orientations in Practice



Note. Adapted from Friedrichsen et al. (2011) and Lotter et al. (2007).

Methodology

In order to understand the extent that topic-related curricular changes outlined by NGSS had taken place, individual chemistry teachers' reported implementations as enacted curriculum are explored using self-reported survey data. Time spent on various topics is used to understand teachers' perceived value of each topic as well as to compare the relative depth of topic coverage in their curriculum. This provides insight into the extent that a set of reform-based standards have been incorporated into everyday classroom experiences for students. Individual interviews are used to probe teachers' orientations such as the goals of teaching and learning science (chemistry) and what factors influence the time they allocate within their curriculum. Topic coverage and teachers' stated purposes for teaching and learning science and chemistry provide insight into the extent that current reform efforts (NGSS) have influenced the enacted curricula of individual science teachers within the state of Illinois in the United States.

This study was guided by the following research questions:

1. To what extent are the NGSS performance expectations (incorporating physical science disciplinary core ideas related to chemistry) integrated in Illinois chemistry classes five years after adoption?

2. How does a teacher's orientation to the teaching of chemistry, specifically their views of (a) the goals or purposes of chemistry (science) teaching and (b) science teaching and learning impact their curricular design choices?

We chose to use the PEs to organize the topics because the DCI's are either too general, (i.e. PS3.A: Definitions of Energy) or too specific (i.e. PS3.B: Conservation of Energy and Energy Transfer) for survey creation. By using the PEs, the traditional chemistry topics could be more clearly identified and allow for greater clarity in responses from teachers. Based on the purpose of the study, an explanatory mixed-methods design was used (Plano Clark & Creswell, 2010). With Institutional Review Board (IRB) approval, a self-reported online survey about Illinois chemistry teachers' current curricular practices five years after the statewide adoption of NGSS was administered using Qualtrics, an online survey platform. Once created, the survey was piloted by five practicing secondary chemistry teachers to obtain feedback relating to question clarity, ease of use, and survey length. Following this pilot, revisions were made, and the survey was distributed to potential participants that were reached through listservs and direct email. Survey data was collected throughout February 2019. The qualitative interview methodology allowed for the subsequent collection of data about the ways in which some teachers are similar or differ in their curriculum design and orientations to the teaching of chemistry.

Survey Instrument

The survey instrument used included demographics questions (e.g. school location, years of experience, etc.) as well as questions that explored the specific chemistry content taught and the instructional time spent on each topic within a typical school year (See Appendix A for complete survey instrument). Questions relating to content and instructional time were asked of teachers that taught introductory chemistry, honors chemistry, advanced, and/or Advanced Placement (AP) or International Baccalaureate (IB) chemistry. These topics were representative of the typical content that might constitute a portion of any potential chemistry course offered at the secondary level (Table 2 in the results has the list of topics and their alignment to the PEs). An option for "other" was offered for respondents that wished to provide additional content areas that were not specifically included in the survey instrument (See Appendix A). Using instructional time as a proxy for the level of incorporation of extent each topic in the course, participants were given the choice, as ordinal-level variables, of time spent on the topic as "0 Days", "1-2 Days", "3-6 Days", "7-10 Days", "11-15 Days", and "More than 15 Days". Responses were consolidated into "0-2 Days", "3-10 Days", and "11 Days or More" for clarity.

Questions about the extent that respondents felt their overall curricular goals were achieved, the ways in which local curricular collaboration occurs, and the changes made since the state's adoption of NGSS were also included. Additional questions asked teachers to identify chemistry topics that individual teachers most and least enjoyed as well as those that they would devote additional instructional time to if the school year were extended by several days.

Semi-Structured Interview

The qualitative interview utilized a script of approximately 12 open-ended questions in which teachers' specific orientations to the teaching of science and approach to curriculum design were explored in greater detail (See Appendix B for Interview Protocol). Questions were, in part, derived from previous research relating to teacher beliefs and orientations (Luft & Roehrig, 2007). Other questions were designed to elicit specific information about enacted curriculum in teachers' classrooms as well as any influence felt by new curricular standards.

Participants

The survey was distributed to Illinois chemistry teachers using state chemistry teacher organization and state science teacher email listservs, direct solicitation, and existing email contacts with encouragement to forward it to other chemistry teachers. Respondents that completed the survey were eligible to submit their email address for an opportunity to win an Amazon gift card. A total of 128 Illinois chemistry educators responded. Survey responses were completed by teachers of introductory chemistry (94.5%), advanced chemistry (19.7%), and AP/IB chemistry (24.4%). Of the respondents, 30.5% taught at schools where chemistry was required and 37.2% taught only chemistry. Respondents rated their familiarity with NGSS on a Likert-style scale with a 5 being expert-level, 59.0% of all respondents rated themselves as a 4 or 5 while only 8.6% rated themselves as a 1 or 2. Table 1 provides additional demographic information about participants' teaching experience and educational attainment.

Table 1

Survey Participant Demographic Information

Demographic	Value	Frequency
Setting (N=128)	Rural	31.3%
	Suburban	57.0%
	Urban	11.7%
Degree Type (N=127)	Bachelor's	23.6%
	Master's	72.5%
	Doctorate	3.9%
Taken Graduate Course in Chemistry (N=128)	Yes	50.8%
	No	49.2%
Teaching Experience (N=127)	0-3 Years	18.8%
	4-10 Years	28.9%
	11+ Years	52.4%
Familiarity with NGSS (N=117)	Low (1-2)	8.6%
	Moderate (3)	32.5%
	High (4-5)	59.0%

Interview participants were volunteers that self-identified and chose to provide their name and contact information following the completion of the survey instrument in the first phase of the study. Selection of individual teachers for interview was based on convenience sampling (Creswell, 2008). Because far more volunteers were willing to participate in the interview than was possible to interview, individual participants were selected using maximal variation sampling to ensure equal representation from rural, suburban, and urban schools as well as from early-career, mid-career, and veteran teachers as well (Plano Clark & Creswell, 2010). After receiving a completed informed consent form, interviews were completed over the telephone and digitally recorded.

Data Analysis Procedures

Survey data was analyzed using the SPSS software package. Data analysis techniques including descriptive statistics and Pearson chi square to determine if any of the findings were statistically significant at the $p < 0.05$ level or lower (Plano Clark & Creswell, 2010). Interview data recordings were transcribed verbatim and, initially analyzed using a preliminary exploratory analysis (Creswell, 2008). Identified text segments were initially coded for themes using NVivo based on relevance to each research question and their relation to teacher orientations. Initial coding themes were developed based on the patterns of responses for clusters of related code such as: goals and purposes of teaching chemistry (e.g. college preparedness or skill focus) or views of teaching and learning science (e.g. student ability, relevance of content, etc.) (Corbin & Strauss, 2015). As part of an explanatory mixed-method design, the interview portion was used to refine and contextualize results from the survey portion of the study and further develop established themes (Plano Clark & Creswell, 2010). Reported findings and quotations are presented using pseudonymous initials in order to preserve participant anonymity.

Limitations

There are several limitations for this study which should be mentioned. It relies on self-reported data of classroom practices from Illinois chemistry teachers which cannot be guaranteed to be entirely reliable. Focus questions on the survey dealt primarily with content and, as a result, bias the responses toward DCIs over SEPs or CCCs. Interpretations about the extent of implementation of phenomena-based instruction or SEPs or CCCs would not be appropriate given the scope of this study.

Results

The study provided insight into how Illinois chemistry teachers are integrating NGSS into their introductory chemistry classes. First discussed below are survey results detailing NGSS PE coverage in introductory chemistry. Then, the teacher interview results detailing orientations to the teaching and learning of science and chemistry as well as the ways in which teachers individually (and in collaborative groups) approach curriculum design and revision are shared below.

Integration of Relevant NGSS PEs in Introductory Chemistry

Teachers were asked to reflect on the amount of time (in days) spent on specific content (DCI, aligned to each PE) taught in the introductory chemistry course(s) they were responsible for. Not all PEs were covered in the same amount of class time (See Table 2). NGSS-related topics such as bond energy, kinetics, equilibrium, and nuclear chemistry all tended to receive two or fewer days of attention in the chemistry classrooms of teachers surveyed. Other topics found in NGSS, such as stoichiometry, appeared to be addressed much more extensively as 64.5% of teachers reported dedicating 11 days or more of class time to it. Topics not explicitly included in the standards such as atomic structure, nomenclature, and predicting/classifying chemical reactions were reported to receive more class time as well. For example, 44.4% of classrooms spent 11 days or more teaching nomenclature, which would rank higher than any of the NGSS-aligned topics except for only chemical bonding and stoichiometry.

Table 2

Time Spent on Topics in Introductory Chemistry

NGSS Performance Expectations (PEs)	Topic Name	0-2 Days	3-10 Days	11 Days or More
HS-PS1-1 HS-PS1-2	Periodic Trends	12.2%	63.3%	24.5%
HS-PS1-2	Chemical Bonding	2.2%	48.9%	48.9%
HS-PS1-3	Intermolecular Forces	44.9%	50.6%	4.5%
HS-PS1-4	Bond Energy	67.4%	28.1%	4.5%
HS-PS1-5	Kinetics	72.7%	25.0%	2.3%
HS-PS1-6	Equilibrium Chemistry	58.6%	37.9%	3.4%
HS-PS1-7	Stoichiometry	4.4%	31.1%	64.5%
HS-PS1-8	Nuclear Chemistry	55.6%	33.0%	11.3%
HS-PS2-6 HS-LS1-6	Organic Chemistry	84.1%	14.8%	1.1%
HS-PS3-4	Calorimetry	44.4%	40.0%	15.5%
N/A	Acids & Bases	37.8%	51.1%	11.1%
	Atomic Structure	1.1%	46.6%	52.2%
	Gas Laws	33.3%	36.6%	29.0%
	Nomenclature	6.7%	48.9%	44.4%
	Predicting Products of Chemical Reactions	5.5%	55.5%	38.9%

Note. N/A means that the topic is not directly applicable to an NGSS PE.

In more than 40% of the teachers' introductory chemistry classrooms, eight of the identified physical science PEs that align with typical chemistry content (out of 11) were given two or fewer days of class time while many were reported to be not covered at all. For example, bond energy and kinetics were each covered for two days or less in more than 67.4% of introductory chemistry classes surveyed.

Survey respondents were also asked to rank their three most and three least favorite subjects to teach in their introductory chemistry course as well as what topic they would spend additional time on if the school year were extended by a few days (See Table 3). Stoichiometry, gas laws, and predicting/classifying products of chemical reactions were reported to be among the most enjoyed by respondents, receiving a vote from no fewer than 35.0% of respondents, each. At the same time, bond energy (a topic included in NGSS) was the most consistently disliked of all topics with 41.6% of respondents indicating their it was among their least favorite topics.

Table 3
Attitude Toward Topics in Introductory Chemistry

NGSS Performance Expectations (PEs)	Topic Name	Most Enjoyed Topics (Top 3)	Least Enjoyed Topics (Top 3)	Would Spend Additional Time (if available)
HS-PS1-1 HS-PS1-2	Periodic Trends	12.8%	23.0%	0.8%
HS-PS1-2	Chemical Bonding	15.4%	4.4%	4.2%
HS-PS1-3	Intermolecular Forces	12.8%	18.6%	7.6%
HS-PS1-4	Bond Energy	25.8%	41.6%	20.2%
HS-PS1-5	Kinetics	9.4%	14.2%	9.3%
HS-PS1-6	Equilibrium Chemistry	17.9%	18.6%	22.0%
HS-PS1-7	Stoichiometry	48.7%	11.5%	9.3%
HS-PS1-8	Nuclear Chemistry	18.8%	18.6%	17.8%
HS-PS2-6 HS-LS1-6	Organic Chemistry	3.4%	13.3%	22.0%
HS-PS3-4	Calorimetry	11.1%	14.2%	9.3%
N/A	Acids & Bases	24.8%	9.7%	35.6%
	Atomic Structure	8.5%	15.0%	0.8%
	Gas Laws	35.0%	3.5%	17.8%
	Nomenclature	12.0%	23.0%	0.0%
	Predicting Products of Chemical Reactions	35.9%	7.1%	0.8%

Note. N/A means that the topic is not directly applicable to an NGSS PE.

Responses for time spent on each topic in introductory chemistry were compared using Pearson chi square analysis for differences between school setting, teacher level of education, years of teaching, advanced coursework in chemistry, and level of chemistry taught (See Appendix C for complete statistics). Few relationships between the variables were shown to be statistically significant ($p < 0.05$). Significant relationships were found between time spent on bond energy and setting ($X^2_{(2)}$

= 10.197, *p* = .037), time spent on gas laws and having taken a graduate course in chemistry ($X^2_{(1)}$ = 6.497, p = .039), time spent on intermolecular forces and also teaching AP/IB chemistry ($X^2_{(1)}$ = 6.207, p = .045), and time spent on organic chemistry and setting ($X^2_{(2)}$ = 12.051, p = .017). No significant relationships were found between time spent on a given topic and any other variables tested. Because only four of the test statistics were significant out of the 105 tests run in the crosstabulation, it would be reasonable to assume that any significant results were not practically significant.

Table 4

Partial List of Codes, Definitions, Sample Responses, and Frequencies for Answers to: What significant changes, if any, have been made in your school's chemistry curriculum as a result of the state's adoption of the Next Generation Science Standards (NGSS)?

Code	Definition	Sample Response	Frequency
State of Chemistry Curriculum			
Changes Made	Curricular changes have been made to account for the expectations of NGSS	"We have cut down on ALOT of content and really focus on students 'doing' science…rather than knowing about science" "We redesigned our Periodic Table unit to be fully 3D learning"	73.1%
Changes in Development	Curriculum is still being changed to meet the demands of NGSS	"Currently working on revising the science curriculum" "Our district is currently doing a science curriculum review to align to NGSS"	7.7%
No Changes Made	Curriculum has not undergone significant change following the adoption of NGSS	"None…curriculum leaders have no intention of actually changing the curriculum" "Have had to fight to maintain the integrity of [existing] chemistry curriculum…"	19.2%
Types of Curricular Changes Made: Content			
Added Content	Curriculum was modified to add content that had not been part of the curriculum prior to NGSS	"We also added topics like nuclear chemistry and reactions rates…" "Some topics, like kinetics and equilibrium, are introduced earlier than before (intro chem vs. AP)"	14.1%
Removed Content	Curriculum was modified to remove content that had previously been part of the curriculum prior to NGSS	"Eliminating concepts such as sig figs, electron configuration…" "…I have ditched some of the units of tradition…"	21.8%
Emphasized Phenomena	Curriculum was modified to be guided by an observable event for each unit of instruction	"Using phenomena to drive the curriculum" "…most units are driven by a real-world application and examples from every day life are used when possible"	3.9%
Using Other Curricula	Curriculum created elsewhere was used as the basis for school curriculum	"We use the chemistry modeling curriculum from AMTA" "I switched to the Chemistry Modeling curriculum 5 years ago…"	5.1%
Types of Curricular Changes: Emphasis			
Prioritizing Skills	Curriculum has changed to allow for more opportunities for student to develop skills beyond content	"Science and engineering practices and crosscutting concepts are more of a focus" "More emphasis on skills and reasoning/justification"	32.1%
Student Centered	Curriculum has changed to allow students more control of their learning and rely less on direct instruction	"Adapted to more collaborative and discussion moving away from lecture-based classroom dynamics" "I have designed more opportunities for students to present, collaborate, and communicate their findings in class" "…make the class more student-centered and less teacher-centered"	9.0%
Types of Curricular Changes: Assessment			
Assessment	Changes have modified the way(s) that students are able to submit evidence of their learning	"More…3D assessments" "[Changed] expectations of what students should be 'producing' to demonstrate mastery of a standard"	3.9%

Note. Frequency percentages calculated from N= 78 total responses.

Teachers were asked to share any changes they've made to their curriculum as they've begun implementing NGSS in their classes. Table 4 shows a list of all the codes, definitions, sample responses, and frequencies for responses to a survey question asking teachers to report any significant changes (if any) that their chemistry curriculum has undergone since adoption of NGSS. 80.8% of all responses (N=78) reported that their curriculum had undergone some degree of change—or that changes were ongoing while 19.2% indicated that their curriculum had not changed as a result of NGSS. An example response of those that said their curriculum had not changed:

> *We have had to fight to maintain the integrity of chemistry curriculum in spite of the misguided attempt to enforce the minimum standards outlined in NGSS for Chemistry! We shouldn't gut a great curriculum just because concepts are not given enough depth in NGSS.*

Content was added to curriculum in 14.1% of responses while content had been reportedly removed in 21.8%. Skills such as critical thinking using SEPs and CCCs were reported to receive greater emphasis in the curriculum of 32.1% of responses.

Goals and Purposes for Teaching Chemistry: Impact on Curricular Design

Table 5 provides a list of all the codes, definitions, and sample responses from the interview analysis. Interviewees (N=9) were asked about the purpose for teaching or learning chemistry (a part of their orientation, see Figure 1) and codes emerged in which respondents viewed introductory chemistry as either preparation for future chemistry coursework (primarily at the collegiate level) or as an opportunity to develop generalizable critical thinking skills.

Table 5

Partial List of Codes, Definitions, and Sample Responses from Interviews

Code	Definition	Sample Response
	Goals and Purposes for Teaching Chemistry	
College Preparation	Exposure to large amounts of information and content typically associated with an introductory undergraduate chemistry course	"I try to get them enough information and I pound it on them" "If you have a college chemistry class these are some things that you will feel more supported when you get to that content because you have seen it before"
Skill Development	Development of a personal skillset or ability to think critically and apply science reasoning to larger problems or contexts	"…to make a well-informed person…making informed choices" "…experimenting, trying things, fixing, evaluating…" "…to really get the kids…prepared for jobs that aren't around right now"
	Views of Teaching and Learning Science	
Student Ability	Innate characteristics of students or groups of students that drive instructional decisions	"…the kids that don't get it are never going to get it" "We should be teaching to the higher-level student, not tailoring everything to the lower-level student"
Relevance of Content	Individual teacher enjoyment of topics of view of its role within a coherently designed chemistry class	"I'm going to teach it because it's a standard part of a chemistry course anyway and I don't care what NGSS calls it, I'm just going to do it" "I'm not going to go full fling into something that leaves out major ideas that are essential for any chemist"
Perception of Standards	Personal philosophy or interpretations of the extent that NGSS should be used in curricular design	"I'm quite content if my 10th graders have the kind of understanding that NGSS is listing as a 7th grade concept" "I've been picking and choosing NGSS standards that fit my lesson"

For six of the nine interviewees, the primary purpose of taking a chemistry course was to prepare for a future chemistry course at the collegiate level. For example, MD explained:

> *I don't focus a lot on the theory too much, on the background of why. I just focus on the task that we need to complete so that when they leave my classroom, they should be able to go to college and enter a chem 101 class and feel comfortable.*

For the remaining three of the nine interviewees, the purpose of taking a chemistry course fell in line with a need to prepare for a lifetime of employment and/or the development of generalizable skills (See Table 5). Personal decision making and problem solving were cited as the larger goal behind learning chemistry at the secondary level. For example:

> *Maybe 10 years from now or 10 days from now they won't remember exactly what we did in class but the skills of them learning those ideas of being able to look at data and critically analyze it and figure out something that they do not necessarily see with their naked eyes is a very important skill. (JE)*

As another example:

> *I think the purpose of science education is to get students thinking critically about the world around them and doing that through a scientific lens. So being able to analyze data and creating meaning from it...not just in the classroom but also big picture so that they're developing these skills so when they go out into the world and they have these graphs and charts and data sets to analyze they can think critically about what those numbers mean and they have skills to interpret the information. (HP)*

Using scientific reasoning and developing the ability to apply critical thinking to a problem were clear priorities for each of the three teachers that appeared to prioritize development of science process skills in their respective chemistry classes.

Views of Teaching and Learning Science: Impact on Curricular Design

Another part of orientations includes teacher views about the best ways that teachers teach and students learn science. As interviewees (N=9) were asked about their understanding of their role as a teacher, their students' roles as learners, and how students best learn science, codes relating to student ability, relevance of content, and perception of standards emerged (See Table 5).

Three of the interview participants specifically suggested that their perception of their students' capacity for learning chemistry content played a role in determining the depth and breadth of the curriculum as well as their instructional approach. For example, TJ explained that "...the kids that don't get it are never going to get it". A different teacher, MD, described their frustration with having students that they viewed as "pretty low overall" and explained that they don't view many of their students as being capable of what the teacher viewed as "higher-level" work because they felt that they had to "hold [a student's] hand constantly". Similarly, RS wondered:

> *As high schoolers, do you want to do a worksheet you can do or do you want to think? There's always the worksheet that they can do. They just want to answer their questions, get the A, and go. That's not true to all of them, but you notice those more when you are on a phenomena focus because those kids are like 'WHAT WHY?!' so these are things I think are way more fun the way that we're doing.*

Interviewees overwhelmingly cited the relevance of content that they felt constituted a chemistry course as the basis for their enacted curriculum. Five teachers cited essential ideas and concepts that existed prior to the development of NGSS as the basis for a chemistry class of any type. For example, LR wondered:

> *How do you have a chemistry curriculum with standards that don't mention the word moles...I mean that doesn't make sense, so there's every chemistry teacher I know whenever I talk to them about this, what they are doing to sort of, take the best of NGSS and incorporate that into their classroom, but they are not going to give up the things that they know in their heart are good chemistry concepts, but just don't happen to be represented in NGSS, you know?*

Of those, three specifically explained that several specific performance expectations (PEs) and disciplinary core ideas (DCIs), such as equilibrium or kinetics, were not included in their curriculum because those PEs or DCIs didn't align with their view of what a chemistry course ought to be.

Six of the participants, including all five from the preceding paragraph, referenced their personal interest or desire to teach certain topics over others as a significant reason for spending a given amount of time on a specific topic. GP gave an example of this by explaining that "I really like stoichiometry because I like the numbers. I like being able to do the calculations and stuff like that". Another example involved making sure that their students are engaging in ideas that have practical relevance to students' lives beyond academics. LR explained:

> *I've started to focus...on climate because I just don't think, as a science teacher, I can't just teach my class and call it a day anymore—and that's a radical shift for me. I used to just bounce all around the map with stuff that I did in those segments of my teaching, but I just feel like as a society, we science teachers that owe it to the rest of society to kind of impress upon the new generations that like 'No! This is the most urgent thing on the planet!' and we need to be thinking about it more.*

Among the ways that participants described topics of interest, four specifically cited their own personal philosophies or their own interpretations of the standards as a justification for their approach to what topics should be included in their curriculum following the state's adoption of new standards in 2014. Two examples of this are:

> *This textbook just goes to the basics and that's really all I incorporated. I never did nuclear prior to when NGSS came up because there's a big stipulation on there on nuclear on doing half-life and things like that so that's when I incorporated it. (MD)*
>
> *There's things that maybe I spend time on that I shouldn't according to NGSS. I spent some time on significant figures...something that I feel like is important and then I know that kids in my introductory chemistry have not been exposed to significant figures so I feel like it's important in lab and to measurement to be able to do stuff like that. So that is stuff that I spend time on that maybe I shouldn't according to NGSS but I feel like I don't get through all the material that I want to in chem 1. (GP)*

Discussion

Evidence from this study suggests that the process of implementing NGSS in chemistry classes across the state of Illinois remains a work in progress. Even though they claimed strong knowledge of NGSS, teachers' self-reported survey responses suggest that many topics mandated by NGSS such as bond energy, equilibrium chemistry, kinetics, nuclear chemistry, and organic chemistry are not being integrated into teachers' enacted curricula (Table 2). Similarly, topics such as nomenclature and predicting products of chemical reactions are covered far more extensively despite their lack of explicit inclusion in the state standards. The only topic covered explicitly in NGSS that received comparable attention is stoichiometry; more than 60% of introductory chemistry classrooms report spending 11 or more days covering this topic. Three of the PEs (bond energy, equilibrium chemistry, and organic chemistry) that ranked among the least in time spent in introductory chemistry classrooms were selected as topics that teachers would consider allocating additional class time toward if the school year were unexpectedly extended by several days. This indicates that many teachers may be aware that they may not be adequately covering some of these topics and view themselves as having to make choices in coverage.

Responses were consistent between different subgroups (school setting, teacher level of education, years of experience, etc.) as evidenced by the lack of statistically significant differences in responses. This suggests that it is likely representative of the PE coverage in the variety of chemistry classroom environments throughout the state of Illinois. These results mirror those of a similar study done with Iowa teachers prior to the adoption of NGSS (Boesdorfer & Staude, 2016). Evidence suggests that many teachers have made or are continuing to make changes to their curricula as a response to new standards (Table 4). Despite that, it seems that the adoption of new standards alone has not caused a substantial shift in topics covered in introductory chemistry courses across the state. An Illinois teacher, JE, in an interview response may been hyperbolizing a bit when explaining that "if anybody says they are doing NGSS in the classroom...I don't think they are", but that sentiment may not be as far from reality as it might seem. As with past reform efforts (Datnow et al., 2006; Finnan, 2000; Fullan, 2007; McLaughlin, 1987), these results suggest that the enacted curricula of individual teachers are influenced by more factors (such as orientations) than just the existence of state standards.

Based on interview responses, six out of nine participants believe that goals for teaching and learning science—and chemistry in particular—emphasizes the preparation of students for rigorous study in college. Using Figure 1, the purpose of teaching or learning science can be viewed along a continuum from amassing information to developing problem-solving skills (critical thinking). Two-thirds of participants positioned themselves closer to the amassing information end of the continuum despite the fact that research suggests that amassing information is not the most appropriate way to prepare students for collegiate-level work and is less important than science reasoning (Cracolice & Busby, 2015; Lawrie et al., 2019). This is reinforced by studies (Tai et al., 2005; Tai, et al., 2006) that show that a student's high school chemistry experience has an impact on their success at the collegiate level, but that the secondary chemistry teachers' view of what is important for success do not match those of university professors that teach introductory chemistry (ACT, 2009, 2012, 2016).

These orientations towards science teaching seem to be impacting the decisions of teachers more than the standards, themselves. This is problematic for introductory classes taken by most high school students and includes those that intend to pursue collegiate study as well as those who don't. According to the Illinois State Boarded of Education (2019), 26% of all high school graduates in Illinois do not plan to enroll in postsecondary education. For non-college bound students, these introductory classes may not be as welcoming, or the covered concepts perceived to be inherently for other students. This gap in perception suggests a need to fundamentally question the collective wisdom of the canon of knowledge that appears to drive chemistry instruction in high schools. Additionally, there appears to be a need for more clear communication between secondary and post-secondary chemistry teachers.

Attempts to understand the extent that NGSS has been implemented in chemistry classes across the state of Illinois must be understood in context of the curriculum enacted in classrooms. In response to the questions about the various considerations used to revise or design their chemistry curricula, teachers appear to be influenced by their individual orientations in context of their views of teaching and learning in science. Teacher views about the best ways to teach and learn in science classes can be viewed through a lens of student ability (limited ability vs. capacity for expanding ability) and what constitutes learning (information is transmitted vs. independently constructed) (See Figure 1). Interview responses from three participants indicated a tension between both views of student capacity in curriculum design (See Table 5). One teacher argued that students they identified as "higher-level" are the more appropriate target for instruction than those they describe as "lower-level". Rather than tailor instructional sequences to be accessible to all students, it seems that some teachers may solve the problem presented by certain concepts in NGSS that require what they believe to demand a higher cognitive load by simply avoiding those concepts altogether.

Five of the nine interview participants specifically described their view that it was important to transmit a certain body of information to students, often described using "Chemistry" as a proper noun to describe the material they believed to be essential for students. Others described a willingness to deemphasize topics that fall within the traditional introductory chemistry canon (such as nomenclature) in effort to better align with the expectations of NGSS. This reinforces the idea that the implementation of NGSS is incomplete and mediated, at least in part, by a canonical body of chemistry knowledge. This is referenced repeatedly by interviewees who believe that NGSS is deficient in some ways because they feel that it "leaves out major ideas" or that teachers feel they need to simply "pick and choose" what standards fit their existing lessons. These results mirror that of previous scholarship on individual teachers' orientations to the teaching and learning of secondary chemistry (Deters, 2003) and science, generally (Friedrichsen et al., 2011).

The results of this study suggest further discussion and professional dialogue must take place in order to help teachers transform their science teaching orientations (goals of teaching and learning science, nature of science, and science teaching and learning). Questioning the purpose of an introductory science course like chemistry is an essential step—are these courses simply an opportunity to learn science through a chemistry-centric lens or do they offer an opportunity to preview some of the content frequently taught in introductory science courses at the collegiate level? In today's educational landscape, it appears more critical than ever to be able to offer a compelling reason for what students are asked to learn. Practitioner journals, professional conferences, and regional professional learning committees could be ideal opportunities to work with colleagues to challenge each other's underlying assumptions and presumptions that may or may not serve our students' best interests.

Conclusion

The evidence presented in this study shows that the enacted curriculum of Illinois introductory chemistry teachers does not align well with the goals (PEs) of NGSS. Much of the chemistry content outlined in NGSS appears to be underemphasized in comparison to other topics that fall outside of those standards. As a result, students may be leaving their high school science classrooms without sufficient opportunities to develop understanding of core ideas and achieve the related goals in the standards. Evidence from this study suggests that the enacted curriculum, which is not aligned with NGSS, appears to be driven more by individual teachers' orientations to and views of teaching and learning of chemistry than by the state standards alone. These orientations have a mediating influence on teacher decision making, which seems to be reinforced through the widespread view that the goals of introductory chemistry require the preparation of high school students for postsecondary chemistry coursework. These findings mirror those of previous studies of the implementation of reform-based standards (Roehrig & Kruse, 2005; Roehrig et al., 2007; Lowe & Appleton, 2014; Veal, et al., 2015). It appears that views about the purpose of teaching and learning science as well as the existence of a canon of chemistry knowledge continue to exert a profound influence on the ways in which secondary teachers shape their curriculum. While the implementation of reform-based standards has clearly not failed in Illinois, full implementation requires the focus of ongoing professional development to help shift teachers' orientations and engage in critical discourse and collaboration amongst professional communities already eager to help students succeed.

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Michael B. Burt (mbburt@ilstu.edu) is a doctoral candidate at Illinois State University and a science teacher at Normal Community West high School in Normal, IL. His current research interests relate to the curriculum development and design decisions of secondary science teachers, particularly in chemistry classrooms.

Sarah B. Boesdorfer (sbboesd@ilstu.edu) is an Assistant Professor of Chemistry Education at Illinois State University. Her research interests include chemistry and science teacher learning and development and how it impacts their practice. She teaches both preservice and inservice teachers.

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Appendix A

Survey Questions

1. How would you classify the school you teach in?
2. Approximately how large is your school's population?
3. Are all students at your school required to take at least one year of chemistry?
4. How many years (including this year) have you been teaching?
5. How many years (including this year) have you been teaching chemistry?
6. What is your highest degree?
7. In what are of study have you earned a bachelor's degree? (Check all that apply)
8. Have you taken graduate-level courses in chemistry?
9. Which of the following chemistry classes are you currently teaching? (Check all that apply)
10. During the current school year, what classes do you teach besides chemistry?
11. What classes have you taught in the past that you are not teaching in the current school year?
12. In your Introductory or First-Year Chemistry classes, how much time do you spend (in a typical year) on each of the following concepts (including assessment and any other instructional time)?
13. Question 13 repeated for Honors (Introductory or First-Year), Advanced (Second Year or Beyond), and/or Advanced Placement (AP) or International Baccalaureate (IB) Chemistry classes (if applicable).
14. Please select the three (3) chemistry topics you enjoy teaching the most.
15. Please select the three (3) chemistry topics you enjoy teaching the least.
16. In a typical year, do you make it through the entirety of your school's chemistry curriculum?
17. If your school year was extended by 5-7 days, what two (2) topics would you be most likely to spend the additional time on in your chemistry class?
18. How much control do you have over your school/district's chemistry curriculum?
19. How familiar are you with NGSS?
20. Is your school or school district's curriculum currently aligned to NGSS?
21. How often do you (or your team) revisit your existing chemistry curriculum and make revisions (if needed)?
22. Are you satisfied with the way that your building stakeholders collaborate on chemistry curriculum?
23. What significant changes, if any, have been made in your school's chemistry curriculum as a result of the state's adoption of NGSS?

Appendix B

Semi-Structured Interview Question List

Note: Questions a, b, etc. only used as necessary.

1. What do you believe is the purpose of science/chemistry education?
2. How do you describe your role as a teacher?
3. What should students know and be able to do when they learn science?
1. In your classroom, how do you decide what to teach and what not to teach?
    a. How do you know when your students understand?
    b. How do you decide when to move on to a new topic in your classroom?
    c. How do your students learn science best?
    d. How do you know when learning is occurring in your classroom?
2. What level of chemistry do you teach?
3. Do you typically get through your entire chemistry curriculum in a given year?
    a. If yes, what do you use the additional time for?
    b. If no, how do you make modifications at the end of the year?
4. What topic(s) do you spend the most time on? The least?
5. Tell me about your unit on _____________.
6. Of the content that you teach, what topic(s) take students the longest time to master/understand?
    a. What makes those topics so difficult?
    b. How have you changed your instruction over the years to attempt to address this?
7. (For Veteran Teachers) How has your curriculum changed over the years?
    a. Are there any topics that you did not teach prior to NGSS that you now teach?
        i. If you had your choice, would you stop teaching it?
    b. Are there any topics that you taught prior to NGSS that you no longer teach?
        i. If you had your choice, would you still teach them?
8. At the end of the year, are there any topic(s) that you don't have time for?
    a. Why?
    b. What adjustments do you make as you finish the year?
9. Is there anything else you would like to say about your curriculum or teaching?

Appendix C

Table 1
Chi Square Test for Relationships between Time Spent Teaching Topics in Chemistry and a Variety of Variables

Topic	Setting	Degree Type	Teaching Experienc e	Graduate Course in Chemistry	Also Teach Honors Chemistry	Also Teach Advanced Chemistry	Also Teach AP/IB Chemistry
Acids & Bases	1.663	8.818	7.742	0.156	1.369	2.516	2.471
Atomic Structure	2.565	12.489	13.350	1.342	0.281	0.310	0.853
Bond Energy	10.194*	9.222	11.117	0.519	1.109	1.414	1.025
Calorimetry	2.498	13.649	9.668	0.392	0.282	1.054	0.686
Chemical Bonding	6.589	7.300	7.398	2.124	0.753	0.686	0.377
Equilibrium Chemistry	4.934	4.860	5.100	1.284	5.288	4.199	0.859
Gas Laws	1.653	11.710	11.980	6.479*	0.682	1.133	2.891
Intermolecular Forces	5.361	3.292	7.201	1.078	0.499	2.468	6.207*
Kinetics	2.863	9.051	13.817	0.017	0.945	1.124	0.542
Nomenclature	4.439	4.668	10.786	2.338	1.209	0.741	0.521
Nuclear Chemistry	4.041	9.703	7.520	3.659	2.839	2.313	0.306
Organic Chemistry	12.051	7.206	8.861	1.225	0.450	2.381	3.150
Periodic Trends	2.575	9.819	6.962	0.807	4.998	0.363	0.274
Predicting Products of Chemical Reactions	7.797	13.100	5.113	0.067	3.371	1.645	2.127
Stoichiometry	7.408	6.407	7.276	4.085	5.134	1.874	0.306

*$p < .05$.