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Cultivating Teacher Expertise in the Landscape of Green Chemistry: The Development of Pedagogical Content Knowledge in Beyond Benign's Lead Teacher Program

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CULTIVATING TEACHER EXPERTISE IN THE LANDSCAPE OF GREEN CHEMISTRY: THE DEVELOPMENT OF PEDAGOGICAL CONTENT KNOWLEDGE IN BEYOND BENIGN'S LEAD TEACHER PROGRAM

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Ad Majorem Dei Gloriam

Fortunately, the Sun does not demand payment for all the energy that it delivers by radiation to Earth in the overall cosmic scheme, which is trying to make humanity a success despite our overwhelming ignorance and fear. The stars are trying to tell humanity to awake and prosper and consciously assume the important cosmic responsibilities for which it was designed. Since realization and fulfillment of that responsibility involve evolutionary discovery by humanity of the cosmic stature of its mind and the inconsequentiality of its muscle, the planting of humans on Earth may not bear fruit.

—R. Buckminster Fuller, *Critical Path*

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LIST OF ABBREVIATIONS

ACS	American Chemical Society
BB	Beyond Benign
CoRe	Content Representation
K-12	Kindergarten through twelfth grade
LT	Lead Teacher
LTP	Lead Teacher Program
LUC	Loyola University Chicago
NAAEE	North American Association for Environmental Education
NGSS	Next Generation Science Standards
PaP-eR	Pedagogical and Professional-experience Repertoire
PCK	Pedagogical Content Knowledge
SDGs	The United Nations' Sustainable Development Goals

ABSTRACT

The Lead Teacher Program (LTP) is organized by Beyond Benign, an institution that promotes green chemistry principles and sustainability in education. LTP trains K-12 teachers to run workshops in their own communities across the US and Canada. This research project aimed to study the culture among K-12 science teachers in LTP and how they share new beliefs, knowledge, and skills in organized settings like workshops and in ongoing ways with peer teachers in their communities. Our research team focused on Pedagogical Content Knowledge (PCK) as the subset of teacher expertise that captures how they teach in content-specific ways. As a case study, we followed a group of teacher leaders working in LTP to better understand how these practices were transformed and shared between peer teachers. My three main research questions were: (1) How does PCK transfer and transform between K-12 teachers in an empowering, peer-led community? (2) What effects does teacher empowerment have on their classroom teaching practices and PCK? (3) Which organized program activities and other community interactions support teachers' sharing and development of PCK? I investigated these questions through a mixed methods approach that considered descriptive data about teachers' knowledge of PCK related to green chemistry, qualitative classroom observations, and personal interviews with teachers. Studying a scalable, geographically-diverse, peer-led, sustainable, and innovative community focused on green chemistry education can help us understand better how to create and maintain similar educational communities in a wide variety of contexts.

CHAPTER 1

INTRODUCTION AND PROJECT HISTORY

"The program doesn't turn these teachers into exceptional teachers. They come in as exceptional teachers and then we open other doors for them." –Beyond Benign Staff Member

Characteristics of an Exceptional Chemistry Teacher

What makes an exceptional chemistry teacher? Is it intelligence or their deep knowledge of chemistry? Is it some aspect of their teaching style or an enthusiasm or charisma that draws students in? Is great teaching an innate characteristic or something that can be developed?

Of course, a definitive answer, if it exists, is likely a combination of these characteristics and unique to different contexts. Ultimately, there is not a normative list of characteristics that can define a great chemistry teacher and certainly no static model exists. In my work with teachers, I have become convinced that good teaching does in fact develop over time. The more important focus is how to develop teachers within their school and individual expertise. What works for one teacher in one setting would not work for another. Yet the study of teaching and learning is not simply doomed to drift in a sea of contextual relativism. I have also seen how teachers share and develop their practice with others for the ultimate benefit of their students. When good teachers develop, the whole world benefits.

My research interest in this project are the factors that support the development and cross-pollination of good teaching practices within chemistry. I believe in chemistry as a critical field for the future in its understanding of the physical world and how we as humans can shape it for better or worse. If we understand better what it means to teach chemistry well, then we can strengthen one more tool in the quest to preserve and improve life for all beings. To begin, I start with one chemistry teacher who describes their approach to chemistry labs:

> This is the schoolwide green chemistry focus of our curriculum that we've all embraced and embedded: Every one of our labs that the kids do is a green chemistry replacement lab. We point out to kids what the traditional method was and how kids would do it, and then the kids write a regular high school chemistry lab report. We have added a final component that's called the Green Chemistry Connection. The kids have to identify two green chemistry principles and explain how the lab adhered to that principle or maybe they think of a way that this lab could be altered even further that would make it be even better.
>
> For example, in the coming week, we're going to be doing the typical formula of a hydrate lab, and the typical method is to use copper sulfate pentahydrate and to dehydrate it using a Bunsen burner. Ahead of time in their prelab exercises, the kids are completing an SDS [Safety Data Sheet] worksheet where they're looking up magnesium sulfate heptahydrate, which is Epsom salt, and copper sulfate pentahydrate. We'll have them look up first aid measures and that kind of stuff. Then we'll talk about how traditionally it is this other chemical, and then it traditionally would use a Bunsen burner, but we're going to use a hot plate.
>
> And then they do the lab. They dehydrate the magnesium sulfate heptahydrate, or we usually just buy Epsom salt from the local drug store, which usually is not exactly a one to seven ratio either. Then we can have a discussion on lab grade chemicals versus the quality control with pharmacy grade Epsom salts.
>
> Then it's interesting because the kids will note, of course, that the copper sulfate pentahydrate has a much higher LD50 than magnesium sulfate heptahydrate. They'll focus in on those types of things, but then some of the kids (I'm sure because I've done this a number of years) will also think about the use of the Bunsen burner versus the hot plate.
>
> And then it gets really interesting, when you see how they creatively look at that, because some kids will focus on inherently safer chemistry for accident prevention, and they'll talk about that the hot plate is a lot more easy to control than the Bunsen burner. Some of them might focus on the principle that connects to energy efficiency. Which then it will be interesting because some kids might say, "using the Bunsen burner would actually have been better because you could have heated it up and evaporated the water faster." But then some kids might say, "using the hot plate was better because you were able to do it at a lower temperature."
>
> The bottom line is: I've never done a thermodynamic energy study on it. I don't know what the right answer is. It's really great inquiry for the kids. It gets them

> really thinking, and as long as a kid backs up the principle that they stated with a logical explanation, they're gonna get credit for it.

This teacher begins to define what green chemistry can look like in a classroom. Stories and descriptions from active teachers will be a major feature of this project to describe and share teaching practices grounded in real community contexts.

Personal Motivation and Lessons Learned from Thesis

Through my research for my master's thesis (Nahlik, 2017), I learned about how teachers approach environmental issues in science classes at Jesuit high schools throughout the US and Canada. My focus was the competencies, as in knowledge and skills, that students were supposed to learn in these classes. This focus on curriculum naturally led to conversations with the teachers about their school context and resources they needed. In my reflection on that work, it became clear that teachers often had the energy and interest to teach critically about science in connection with the natural world. However, many of these teachers felt isolated, under-resourced, and hesitant about their ability to adapt their classroom practice to address large socio-environmental challenges. The lingering questions from that work moved me toward an interest in teacher support and training through the research-based practices.

A major focus of modern science education is to prepare students to solve problems in the world, where issues like climate change threaten to disrupt many facets of our society. To achieve that goal, students need to understand a certain amount of science content, learn content-specific skills, and internalize beliefs about the world. These areas of competencies are reflected in recent educational initiatives in the US, such as the Next Generation Science Standards (NGSS) which describe three similar areas of Disciplinary Core Ideas, Science and Engineering Practices, and Crosscutting Concepts (NGSS Lead States, 2013; Willard, 2014). Much research has focused on the process of student change and establishing practices that teachers can use to support student growth, especially through pedagogical content knowledge (PCK) (Shulman, 1986; Coe et al., 2014; Magnusson, Krajcik, and Borko, 1999; Barendsen & Henze, 2019; Demirdöğen, 2016; Aydeniz, 2014, Jong et al., 2005). Ultimately then, teachers should implement these research-based practices to improve students' abilities in these areas. The problem is sharing these practices with more teachers to respond in a timely way to the pressing need for solutions to global issues.

Yet the major problems in our world are not primarily technical or scientific. They are moral and ethical issues. We currently have the scientific knowledge and resources to solve climate change and world hunger and to ensure a thriving future for all beings on our planet. I share Buckminster Fuller's (1981) perspective that:

> Technologically we now have four billion billionaires on board Spaceship Earth who are entirely unaware of their good fortune. Unbeknownst to them, their legacy is being held in probate by general ignorance, fear, selfishness, and a myriad of paralyzing professional, licensing, zoning, building laws and the like, as bureaucratically maintained by the incumbent power structures. (pp. xxv-xxvi)

What we lack is the moral and social will-power to change these power structures to work better for the future of our planet. Therefore, I am interested in science curricula with a deep content focus that also connects with an ethical and moral framework to address these issues wholistically. One prominent program that fits this interest has been organized by a non-profit called Beyond Benign.

Research Partner: Beyond Benign's Lead Teacher Program

Beyond Benign is a leader in green chemistry education. It was founded by Drs. Amy Cannon and John Warner in 2007 and "is dedicated to fostering a green chemistry community that empowers educators to transform chemistry education for a sustainable future"

(Beyond Benign, 2021). Their programming promotes green chemistry principles in K-12 schools, higher education, and industry to create "a world where the chemical building blocks of products used every day are healthy and safe for humans and the environment" (Beyond Benign, 2021). The Lead Teacher Program (LTP) began in 2016 to help train K-12 educators in principles of green chemistry and empower them to share that expertise with other teachers. In conversations with Dr. Patrick Daubenmire and myself, the program staff expressed interest in having research-informed assessment of their programs to improve and share them more widely. A mutually-beneficial partnership developed out of these conversations.

Particularly at the K-12 level, LTP seemed to address many of the questions that I had about training and supporting teachers. Two features of LTP make it distinctive: (1) The empowering train-the-trainer approach (Koerner et al., 2014), which has already been shown to be scalable in its brief history, and (2) various entry points for teachers to learn about green chemistry, making the program accessible and adaptable. A compelling argument for this training approach is its potential to create a culture of teachers and students who are better able address the impacts of climate change and other socio-environmental issues through chemistry.

Teachers in the program participate in a wide variety of activities, which include developing curriculum, presenting webinars, and joining monthly phone calls with other program participants. As one of the program staff reminds the teachers at each monthly call, the main program goals are to:

1) Empower others to implement green chemistry in the classroom
2) Equip other educators by sharing green chemistry resources
3) Create Beyond Benign materials

These activities and the program will be explored more fully in chapter 5. By working at the K-12 level, LTP seeks to integrate green chemistry principles into early levels of science education.

They emphasize the importance of starting at this level in order to influence higher education, industry, and the whole planet.

To better explain this program, I start with the role of chemistry in the current educational context and consider some educational background in chapter 2.

Ethical Chemistry as a Key to Sustainability

As the study of the interactions and transformations of the physical world, chemistry provides a critical perspective for understanding the fundamental balance of energy and life on our planet. Chemists can study the complex balance of gaseous reactions in the atmosphere or the efficiency of reusing metal ore and other natural resources. In that sense, chemistry is a powerful tool for understanding and shaping the natural world. It helps produce knowledge and objects that can further improve our lives. Inventor and philosopher, R. Buckminster Fuller, wrote extensively about the role of technology and science in human society, especially on what he called humanity's "critical path" (1981), which he described in this way:

> Neither the great political and financial power structures of the world, nor the specialization-blinded professionals, nor the population in general realize that sum-totally the omni-engineering-integratable, invisible revolution in the metallurgical, chemical, and electronic arts now makes it possible to do so much more with ever fewer pounds and volumes of material, ergs of energy, and seconds of time per given technological function that it is now highly feasible to take care of everybody on Earth at a "higher standard of living than any have ever known." It no longer has to be you or me. Selfishness is unnecessary and henceforth unrationalizable as mandated by survival. War is obsolete. (p. xxv)

He portrayed a powerful vision of science at the service of all of humanity, constantly improving and preserving life in all forms. Although our understanding of the limits of technology and the planet's resources have developed much more in the past forty years, Fuller's optimism about resource availability and technological efficiency provide a powerful motivating force for chemistry in the modern world. Yet this vision also needs ethical guidelines and measurable goals to succeed. In other words, the vision must involve sustainability.

The United Nations General Assembly's "Sustainable Development Goals" (SDGs) offered another global perspective on the type of cooperation and the measurable goals needed to carry out this worldwide vision (2015). The seventeen goals and 169 targets highlighted impacts on people, planet, prosperity, peace, and partnership (United Nations General Assembly, 2015, p. 2). These goals charted an ambitious path to eradicate poverty and hunger by 2030. The problems and solutions identified in the SDGs provide a context and a motivating source for any person in the modern world and particularly for chemists who work closely with materials to improve human lives.

Schools also play a pivotal role in educating the public about these problems and potential solutions, especially in scientific advancements. We need political and financial leaders, professionals, and the general public to understand better these advancements in order to leverage them properly for the benefit of all rather than a few **(**Penick & Leonard, 1993). The problems facing humanity are less and less technological but more and more ethical. For chemistry as a field, the main issues concern the distribution and use of resources more than the amount of resources. As the American Chemical Society (ACS) Green Chemistry Institute explains (2020):

> Historically, industrialized communities have benefited most from chemistry innovations, while developing communities have had comparatively fewer benefits. Developing communities often have had their land's resources depleted and/or polluted, been forced to work in unsafe conditions, and faced many health impacts not borne by the developed world. This disparity must be at the forefront of scientists' minds so they make more equitable and socially responsible decisions going forward. (p. 5)

Chemists cannot pretend to be disconnected from this historical and ethical reality, and our education should reflect that concern too. An ethical approach to chemistry is key to achieving the sustainable outcomes proposed by the SDGs and the vision of human success described by Fuller.

These are not new concerns. In fact, there is a long history of integrating environmental and social topics into chemistry. Green chemistry is an appropriate focal lens that builds on this productive understanding of chemistry to propose industrial principles that optimize the use of chemical knowledge for people and the planet. Chapter 2 considers green chemistry in the context of other movements for sustainability and environmental education.

CHAPTER 2

THE LANDSCAPE OF GREEN CHEMISTRY

"Green chemistry involves the design and redesign of chemical syntheses and chemical products to prevent pollution and thereby solve environmental problems."
–Paul Anastas and John Warner in Green Chemistry: Theory and Practice (1998)

To frame the development and distinctiveness of green chemistry education, I begin with other educational programs that have focused on environmental connections, especially in K-12 classrooms. My purpose is not to show every example of environmental connections in schools. Instead, I plan to glean some insights from educational advances that have already been made and show the distinctive role that green chemistry can play in this larger context.

Making Environmental Connections through Context-Based Science

One large area of research and pedagogy to address environmental concerns can be summarized as context-based science. These approaches seek to provide some type of context to motivate classroom learning in a different way than abstract principles or problems. A biology teacher might have students watch a video about arctic penguins before discussing food pyramids. A physics teacher might share images of arches in historical buildings to begin illustrating forces. Or a chemistry teacher might share the controversy about refrigerant impact on the ozone to start a unit about gases. The critical feature of a context-based lesson is that the context is the initial motivation for the lesson rather than a final application.

The effects of this type of learning on students has been well-researched. In a wide-ranging synthesis, Bennet at al. (2007) give a similar definition:

> *Context-based approaches* are approaches adopted in science teaching where contexts and applications of science are used as the *starting point* for the development of scientific ideas. This contrasts with more traditional approaches that cover scientific ideas first, before looking at applications. (p. 348)

They report on results of research into context-based high school science courses along with a similar category of science-technology-society courses. Their overall results suggest that context-based courses "provide as good a development of understanding as more conventional approaches" (Bennett et al., 2007, p. 362); "foster more positive attitudes to school science than conventional courses" (p. 364); and "promote more positive attitudes to science in both girls and boys and reduce the gender differences in attitudes" (p. 364). These effects on understanding and attitudes in high school students indicate the promising results of using environmental contexts as a starting point for scientific content.

Specifically in chemistry, there have been a variety of approaches within the context-based perspective. A well-known example is the *Chemistry in Context* series from the American Chemical Society (ACS), now in its tenth edition (Fahlman, 2021). One review study compiled thirty-four research articles about context-based approaches to chemistry (Ültay & Çalik, 2012), showing the wide range and interest in this approach. Other studies have considered the impact of context-based chemistry on attitudes and understanding of students in high school (Onen & Ulusoy, 2014) or at the university level (Overton et al., 2009). Professional development programs have also been developed to support teachers to implement a context-based approach in their chemistry classes (Stolk et al., 2011). Chemistry educators have been providing motivating contexts for learning in an explicit way for decades.

There are still many open areas of research in context-based chemistry. It is an ongoing process to decide which examples fit best with certain content. There are also debates about the impact on students' conceptual understanding. It might be that the main impact of contextual teaching is on student attitudes (Juntunen & Aksela, 2013), so some teachers might question the value of changing their approach. What is needed is an approach that more convincingly impacts both student understanding and attitudes. Still, the research and writing in context-based chemistry provide a wealth of resources for green chemistry. For further guidance, I turn to the larger area of environmental education to learn how other teachers and researchers have connected curricular innovations with measurable student outcomes.

What Chemists Can Learn from Environmental Educators about Being Green

Using the Environment as an Integrating Context.

Environmental education is a broad area of research, more common at the primary and secondary levels, that uses local environments to engage students in interdisciplinary studies (for a brief history of environmental education, see Carter & Simmons, 2010). Lessons in environmental education might include a historical understanding of an ecosystem and interactions with human development. Scientific lessons might focus on environmental issues of pollution or the biology of a local ecosystem. Depending on the teacher's approach, both classroom and field experiences can be considered as environmental education. The broad umbrella means that many types of educators and disciplines have been involved with environmental education.

Amidst this long history and broad audience, several sets of standards have been developed to assess student growth. The North American Association for Environmental Education (NAAEE) maintains guidelines for K-12 classrooms about the objectives for this type of learning, updated most recently in 2019. These guidelines offer developmentally appropriate considerations for students completing the fourth, eighth, and twelfth grades. They first describe environmental education as:

> a process that helps individuals, communities, and organizations learn more about the environment, develop skills to investigate their environment and to make intelligent, informed decisions about how they can help take care of it. It has the power to transform lives and society. It informs and inspires. It motivates action. EE is a key tool in creating healthier and more civically-engaged communities. (NAAEE, 2019, p. 8)

The standards and associated performance indicators encompass these four strands of environmental education: (1) questioning, analysis, and interpretation skills; (2) environmental processes and systems; (3) skills for understanding and addressing environmental issues; and (4) personal and civic responsibility (NAAEE, 2019, pp. 17-18). The combination of content, skills, and attitudes makes these standards a powerful representation of the type of transformation envisioned by environmental education.

However, other researchers have argued that no set of standards can really capture the goals of environmental education (Kiefer & Kemple, 1998). Andrzejewski et al. (2009) insist on a wider scope for education and argue that "educators must challenge the Standards movement and redirect the educational discourse from exclusively academic accountability to a broader definition of accountability that embraces social justice, peace, and environmental justice" (p. 304). They propose their own set of principles for educational movements that seek to address global threats to justice and peace. Their critique can be a helpful reminder to educators that student conceptual change is not the final objective for many programs. If a larger vision of transformation is sought, then other types of standards or metrics for education will be needed.

Even with this caveat, many studies have shown the impact of environmental education on students. An extensive study by Lieberman & Hoody (1998) focused on US schools that were "using the environment as an integrating context for learning." Their most interesting finding was that students in these schools had "better performance on standardized measures of academic achievement in reading, writing, math, science, and social studies" (Lieberman & Hoody, 1998, p.viii). It might be expected that integrated and exciting projects would help improve student performance in science. Yet the integrated projects that involved local environments helped improve student performance in other disciplines too.

As one example outside of science classrooms, Rita J. Turner presented her approach to language arts lessons that intersect with the environment in *Teaching for Ecojustice* (2015). Her vision for ecojustice education invites students to write and reflect on ecological issues through engaging with media like videos, articles, and personal testimonies. These activities also intersect with social issues like racial discrimination to help students consider their own perspectives and consider how others might be different.

Like green chemistry, environmental education has not been without critics or internal disagreement. Winter (2007) criticizes the prevalence of rhetoric about sustainability over clear policy in English schools. Walshe (2008) shows the disconcerting variety of student conceptions about sustainability which suggest ineffective educational approaches. Saylan and Blumstein (2011) point to a narrow focus in some classrooms on environmental issues, more than environmental solutions or affective connections to nature. Partly, the broad umbrella of environmental education allows a variety of teachers and approaches to work in ways that might be opposed to each other. Environmental approaches to chemistry will certainly encounter similar issues and would benefit from the extensive research in environmental education to anticipate and address these concerns.

Back to Bases: Inquiry-Based, Problem-Based, and Project-Based Learning.

To understand the broader context around environmental education, we consider other prominent educational movements that have shaped both environmental and science education in recent years. A large subset of these movements can be referred to with the overlapping but sometimes distinguished categories of inquiry-based, problem-based, or project-based learning (Thomas, 2000). These teaching approaches usually involve students solving some type of problem by applying classroom content. Critically, the problem is the driving force for instruction rather than ancillary or as a post-instruction assessment. David (2008) highlights the challenges of project-based learning which requires well-formulated tasks for students rather than “a string of activities with no clear purpose or outcome” (p. 82). Because of the contextual and collaborative nature of these approaches, fully implementing project-based learning can be difficult for an individual teacher without a supportive school and community. Recent research has emphasized the importance of student autonomy in pursuing these projects as well as appropriate self- or peer-assessment methods to encourage students’ reflection on their own work (Kokotsaki, et al., 2016). The cross-disciplinary connections and practical challenges of these approaches echo the work of context-based science.

Many teachers have used a problem-based approach for environmental education because of the coherent perspectives of these two areas. One study argues that problem-based learning “can be one dynamic and active methodology capable of helping environmental education become the key to sustainability, that is, embracing the social, economic and environmental pillars” (Vasconcelos, 2012, p. 230). These approaches developed in a similar educational environment and are a natural fit for each other. Local environmental issues often provide rich, motivating problems for students to apply their scientific understanding. Understandably, teachers have drawn from the best practices of these overlapping educational advances.

Starting with Place-Based Education: Examples of Integrated Learning.

One criticism of both context-based and problem-solving approaches is that they still might be intellectually and physically distant from students' experiences, especially at younger grade levels. Thinking about a context or problem is different from experiencing them in more proximate or sensory ways. Place-based education is an approach that ties contexts specifically to a local community in the hopes of connecting better with student experience and motivating problem-solving in practice (Sobel, 2013). Sobel addresses a criticism similar to other environmental educators that "in recent years, environmental education evolved into issues and catastrophe education—learning about rainforest destruction, ozone depletion, toxic waste, and endangered species" (p. 13). He also emphasizes the immediacy of the focus of place-based education: "you don't learn about ecology so you can help protect nature in the future. You learn so you can make a difference here and now" (p. 18). As opposed to an extractive view of resources, "embracing sustainability as an organizing principle means that we accept a concept of limited resources and start to look for ways to simultaneously enhance economic vitality, environmental quality, and school improvement at the local level" (p. 25). Sobel argues that younger grade levels should cultivate environmental awareness closer to a child's home and move to progressively larger contexts at higher grades (p. 29). He also connects the importance of classroom interventions rather than out of school environmental programs (p. 49). His perspective is that environmental education is uniquely positioned to encourage the synergy among classroom problem-solving opportunities and community needs for economic development (pp. 82-83). The niche of place-based education addresses many of the themes of environmental education in connection with local issues.

In summary, recent movements for environmental education have built on different bases of inquiry, problem-solving, projects, and local communities to ground student learning. Many encouraging best practices have emerged along with some clear cautions or concerns. Within this wider context of environmental education, I now consider the distinctive role of green chemistry for student growth.

Green Chemistry Education: From Industrial Principles to Educational Values

Green chemistry originally developed from an industrial perspective and includes twelve principles to think about and use chemicals in a more sustainable way (Anastas & Eghbali, 2010; Anastas & Warner, 1998). Groups like the American National Standards Institute and the American Chemical Society's Green Chemistry Institute worked to develop voluntary standards for green chemistry practices in industry (Taylor, 2010). In some ways, chemistry had developed a bad reputation as being unnatural or inherently harmful. Green chemistry sought to redefine this view. Aubrecht et al. (2019) give this definition: "the practice of green chemistry stresses thoughtful design of molecules, materials, and processes to minimize adverse outcomes in humans and the environment through identification of the origin, transformation, and fate of atoms" (p. 2873). For chemists, the perspective that all manipulation of matter involved the use of chemistry did not translate well to a public that had seen the negative impacts of some chemical processes.

Chemistry education also needed to contend with this negative image. As Haack and Hutchinson note, "the strategies of green chemistry provided a new context for teaching students the concepts and skills of chemistry that cast the discipline in a more positive light while better preparing students to discover and develop sustainable chemistries to meet society's needs" (2016, p. 5890). Green chemistry was both a public relations shift for the field and a call to action for chemists to consider the broader impacts of chemical processes all the way from resource extraction to waste processing.

In this project, green chemistry plays two roles: showing an example of the combination of chemistry and sustainability as well as focusing the scope of the research. Historically, chemistry applications to the environment had often been seen as supplementary or even as a less-rigorous approach to chemistry appropriate for non-majors (such as *Chemistry in the Community*, see American Chemical Society, 2011; and Sutman & Bruce, 1992). A major accomplishment of green chemistry has been to shift this perspective to recognize the challenge and necessity of considering environmental impact as a core part of chemistry (Sharma & Mudhoo, 2011). In a practical way, my project will focus on the content area of green chemistry to bound the scope of my research and to track teacher development more easily. Focusing on the common principles of green chemistry allows me to make comparisons across classrooms of different grade levels and cultural regions.

It will be helpful to frame this discussion of green chemistry with the educational outcomes expected from this approach. In order to define educational outcomes for green chemistry, several core competencies for the undergraduate chemistry curriculum have been developed by the American Chemical Society Green Chemistry Institute (MacKellar et al., 2020), including the following:

1) Graduates will be able to design and/or select chemicals that improve product and sustainability performance from a life cycle and systems perspective.
2) Graduates will understand that chemicals and materials are prepared through transformations of raw materials via synthetic pathways and be able to design and/or select chemical syntheses that are highly efficient, take advantage of alternative feedstocks, and generate the least amount of waste.
3) Graduates will understand how chemicals can be used/integrated into products to achieve the best benefit to customers while minimizing life cycle sustainability impacts. (pp. 2108-2109)

These broad competencies hearken back to the optimistic perspective of science as a productive discipline that can actively improve human society and the planet, rather than only minimizing harm by restricting chemical activity.

The Lack of K-12 Green Chemistry Resources

Green chemistry has become an active research area over the past forty years, in both industry and education. Several recently edited journals and books bring together advances in green chemistry education, especially lab activities for the undergraduate curriculum (Bastin & Dicks, 2019; Benvenuto & Kolopajlo, 2019; Goode et al., 2021, Mahaffey et al., 2019). These volumes show the energy and engagement with green chemistry topics from a variety of subdisciplines. The focus of green chemistry research on undergraduate curricula also makes sense because the twelve industrial principles (as written) would be most useful to someone going into a chemistry profession rather than as introductory concepts.

In fact, not many K-12 teachers are using the principles directly in their classrooms (Anastas & Eghbali, 2010). The role of green chemistry in K-12 classrooms has not been well-documented yet, although this lack of published research could reflect the absence of publication culture among K-12 educators rather than the absence of green chemistry. Among the available K-12 perspectives, one secondary school teacher describes the principles of “prevent waste” and “atom economy” as important for instruction, as well as “benign solvents & auxiliaries” and “inherently benign chemistry for accident prevention” as important for choosing chemicals for demonstrations (Ause, 2018, pp. 186-187). Additionally, green chemistry education research has largely focused on labs and chemical practices in classrooms rather than content or pedagogy (Haack & Hutchinson, 2016). There is a need for further integration of these principles throughout K-12 classrooms.

The K-12 level is a particularly important time to teach students about green chemistry because it might be the last chemistry or science course many of the students take. For a scientifically literate society, we need students to learn about sustainability before the college level. These should be foundational topics, not advanced or niche contexts.

Since green chemistry helps to address the material dimensions of sustainability, there should be some minimum level of understanding we would want most citizens of an industrialized country to have. We need better research about how K-12 teachers can begin preparing students for this work and ensure that students who will not pursue science further have a basis for understanding the molecular nature of sustainability. Teachers also need a list of the essential principles that any scientifically-literate citizen should know. Importantly, those principles should be taught in the K-12 level, especially for students who might never take another science class.

Finally, a green chemistry teaching approach must be connected to specific student learning outcomes to justify its use. Without a clear pedagogical justification, “green chemistry” risks being (or being seen as) simply a Trojan horse to bring any trendy educational practice into science classrooms, similar to criticisms of environmental education (Sanera & Shaw, 1997).

Teachers, administrators, families, and students will want to know if "green chemistry" is simply a marketing tool or another attempt at "green-washing." Other authors have specified the need "to delineate the differences and overlap between *green and sustainable chemistry* because not all *green chemistry* is *sustainable chemistry*" (Green Chemistry Institute, 2020, p. 4, italics in original). For green chemistry to succeed in shifting scientific literacy towards more sustainable considerations, there must be coherent content and clear benefits to students, not just an ideological framework. Fortunately, there are signs that green chemistry is better equipped to address these concerns than previous environmental movements in chemistry.

Is It Really 'Chemistry?' The Place of Traditional Content Knowledge

A major criticism or hesitancy around green and sustainable approaches to chemistry is that it sacrifices traditional content knowledge. Skeptics might complain about a lack of in-depth engagement with chemistry concepts in favor of a cursory engagement that makes room for social issues. A similar practical challenge is how to incorporate additional themes into classes that are already full. Teachers might think that students need to understand the content first before considering more complex applications. The solution must include some amount of cutting or condensing of material. Understandably, some teachers are reluctant to do so. Many science reform efforts have attempted to identify the main chemistry concepts in part to allow for deeper engagement and application to world issues (see especially: NGSS Lead States, 2013).

As adapted by Underwood et al. (2017), the following are the main three dimensions of chemistry content and their associated sub-levels:

1) Core Ideas in Chemistry
    a) Electrostatic and Bonding Interactions
    b) Atomic/Molecular Structure and Properties

    c) Energy: Macroscopic, Atomic/Molecular, and Quantum Mechanical Energy Levels and Changes
    d) Change and Stability in Chemical Systems
2) Scientific and Engineering Practices
    a) Asking Questions (for Science) and Defining Problems (for Engineering)
    b) Developing and Using Models
    c) Planning and Carrying Out Investigations
    d) Analyzing and Interpreting Data
    e) Using Mathematics and Computational Thinking
    f) Constructing Explanations (for Science) and Designing Solutions (for Engineering)
    g) Engaging in Argument from Evidence
    h) Obtaining, Evaluating and Communicating Information
3) Cross-Cutting Concepts
    a) Patterns
    b) Cause and Effect: Mechanism and Explanation
    c) Scale, Proportion and Quantity
    d) Systems and System Models
    e) Energy and Matter: Flows, Cycles and Conservation
    f) Structure and Function
    g) Stability and Change

The authors also provide in-depth examples of how to adapt assessments to measure these three dimensions of learning. One major point is that the goals of chemistry classes should go beyond isolated facts about the physical world. Identifying and focusing on the practices and concepts along with core ideas allows for more time and creativity to incorporate contexts like green chemistry. Ultimately, there is some sacrifice of what most teachers would consider to be the traditional content. However, the more important question should be: is it worth it?

Some teachers have justified the use of green and sustainable chemistry as a motivating force for traditional content learning. Aubrecht et al. (2019) write that "though the primary focus in general and organic chemistry courses is instruction of fundamental chemistry concepts, raising student awareness on the potential of the chemistry enterprise to address global issues involving sustainability can both inspire them and challenge them" (p. 2877). These authors also include charts for the general and organic chemistry curricula to show the overlap of traditional content ("enduring understanding") and green chemistry connections (Aubrecht et al., 2019, pp. 2874-2875). Another study confirmed the positive change in high school students' interest in chemistry and its perceived relevance to their lives through inquiry-based, life-cycle thinking approaches to sustainable chemistry (Juntunen & Aksela, 2013). When used well, environmental problems can provide a motivating context for student learning of content. Such a benefit might convince skeptical teachers that a sacrifice of some conventional content is worthwhile.

Finally, green chemistry also supports an optimistic and economic perspective of chemistry that can actively solve problems in the world rather than simply describing issues. In this way, it is a clear response to concerns about environmental education that convey a pessimistic image of the state of the world. Green chemistry provides an opportunity and framework for students and industrial chemists to invent new solutions that work better for people, the planet, and a community's economic well-being.

With this overview of environmental curricula, a case has been made that green chemistry can address significant concerns in current science education to motivate traditional content learning and foster skills that prepare students to consider the chemistry involved in environmental issues. Chapter 3 introduces the research background for this project designed to develop an actionable understanding of green chemistry principles and classroom practices for K-12 teachers through the lens of the Beyond Benign Lead Teacher Program. This understanding will provide a basis for further research and practice in the development of the field of green chemistry education.

CHAPTER 3

RESEARCH BACKGROUND

"Those who can, do. Those who understand, teach." –Lee S. Shulman

Pedagogical Content Knowledge: The Research of Teacher Expertise

The main research construct and area of focus for my project is pedagogical content knowledge (PCK), which has remained an active area of research since it was proposed by Lee S. Shulman in 1986. Distinct from content knowledge and general pedagogical knowledge, PCK includes content-specific understandings of how students learn a subject, such as common misunderstandings or the progression of topics (Shulman, 1986). Originally, Shulman was concerned about the pendulum swing away from wide-ranging content knowledge as the test of teacher proficiency toward pedagogical knowledge devoid of any content. Instead, he proposed "three categories of content knowledge: (a) subject matter content knowledge, (b) pedagogical content knowledge, and (c) curricular knowledge" (Shulman, 1986, p. 9). He defined PCK "for the most regularly taught topics in one's subject area, [as] the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" as well as "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (Shulman, 1986, p. 9). In this way, he reframed content and pedagogy as interrelated fields of teacher expertise rather than independent skillsets.

The perspective of PCK emphasizes that an expert chemistry teacher is distinguished neither by advanced content knowledge nor by skillful educational strategies but by an area of expertise specific to teaching chemistry at a certain grade level. An experienced chemist cannot simply learn some educational techniques and become an expert teacher. Similarly, an experienced high school chemistry teacher would likely struggle to transition to teaching English even with deep familiarity with the content. Teachers in any discipline require a rationale for their pedagogy that is not transferable from other subject areas. As Shulman (1986) stated:

> The teacher is not only a master of procedure but also of content and rationale, and capable of explaining why something is done. The teacher is capable of reflection leading to self-knowledge, the metacognitive awareness that distinguishes draftsman from architect, bookkeeper from auditor. A professional is capable not only of practicing and understanding his or her craft, but of communicating the reasons for professional decisions and actions to others. (p. 13)

A true test of teaching expertise would be this type of reflective reasoning as described by PCK.

Because PCK is linked with content, it must be studied in content-specific ways that may require unique frameworks. Within science education research, Magnusson et al. (1999) defined the following five components of PCK for science teaching:

1) orientations toward science teaching,
2) knowledge and beliefs about science curriculum,
3) knowledge and beliefs about students' understanding of specific science topics,
4) knowledge and beliefs about assessment in science, and
5) knowledge and beliefs about instructional strategies for teaching science. (p. 97)

These five components delineate the connections that Shulman (1986) implied among content, pedagogy, and PCK. Importantly, PCK does not supplant content knowledge. As other researchers have noted, "the most effective teachers have deep knowledge of the subjects they teach, and when teachers' knowledge falls below a certain level it is a significant impediment to students' learning. As well as a strong understanding of the material being taught, teachers must also understand the ways students think about the content, be able to evaluate the thinking behind students' own methods, and identify students' common misconceptions" (Coe et al., 2014, p. 2). As a defining level of teacher expertise, PCK draws from "the three base domains of teacher knowledge: subject matter, pedagogy, and context" (Magnusson et al., 1999). Expert teachers need deep knowledge in each of these three areas, yet this knowledge alone does not guarantee that a teacher has or will develop the necessary PCK to teach a topic at a certain grade level.

After this concept was better defined and accepted in the academic community, the practical research interest became: are there ways to teach PCK directly in order to prepare teachers better? Instead of each teacher learning independently, could PCK provide a shortcut to develop expert teachers more quickly within a community of teachers in training? Research began to focus on this practical dimension of PCK for teacher training (Neumann et al., 2019). For example, Demirdöğen et al. (2016) used PCK to structure and assess a course for pre-service chemistry teachers. As Magnusson et al. explained (1999):

> The practical value of pedagogical content knowledge as a construct has to do with its potential to define important dimensions of expertise in science teaching that can guide the focus and design of pre-service and in-service teacher education programs. Many science teachers and science teacher educators have a wealth of knowledge about how to help particular students understand ideas such as force, photosynthesis, or heat energy; they know the best analogies to use, the best demonstrations to include, and the best activities in which to involve students. (p. 116)

Studying PCK is one way to access and share this wealth of knowledge with wider communities.

More recent research has identified PCK as a major indicator of student learning. In an extensive literature review on teaching effectiveness, Coe et al. (2014) identified PCK as one of six components of great teaching and one that has "strong evidence of impact on student outcomes" (p.2). Coe et al. (2014) noted the positive impact of physics teachers' PCK and motivation on students' achievement and interest. Therefore, studying a teacher's PCK can be an indirect way of predicting student growth in a course.

However, researchers have been careful to note differences in types of PCK. Aydeniz and Kirbulut (2014) emphasized "that PCK must be understood and explored at two levels: (1) espoused/planned PCK and (2) enacted PCK" (p. 149). Although both areas are important, this subtle distinction clarifies that how a teacher describes their pedagogy might be different from how they enact that pedagogy. To study teacher's espoused PCK, Aydeniz and Kirbulut (2014) developed an instrument to prompt pre-service teachers' reflection on their teaching plan for galvanic cells under the "assumption that by forcing participants to think about specific aspects of reform-based curriculum, reform-based instructional strategies, and assessment strategies in groups, pre-service teachers would develop enhanced PCK for teaching the concept of electrochemistry" (p. 153). The discussions among these pre-service teachers provided a rich context to study PCK development. The common language developed in this study and with similar instruments has been an important contribution of PCK research to developing teacher practice. In an in-depth, qualitative study, Barendsen and Henze (2019) explored how one teacher's "articulated PCK-on-action appears to be more constructivist than his teaching practice" (p. 1164). Even if a teacher has highly developed espoused PCK, there can still be barriers to integrating that knowledge into instructional practice.

Understandably, research on PCK has focused especially on pre-service training or individual administrative interventions (Demirdöğen et al., 2016; Aydeniz and Kirbulut, 2014, Jong et al., 2005). However, more research is needed to understand how PCK is shared between in-service peers beyond one-time interventions and in specific contexts like green chemistry education (Baxter & Lederman, 1999; Loughran, Berry, and Mulhall, 2012). Part of my work involved developing descriptions of pedagogical content knowledge specifically related to green chemistry, inspired by previous research with pre-service teachers (Demirdöğen, 2016; Aydeniz, 2014, Jong et al., 2005; Parga Lozano, 2015). These descriptions will allow future research to more easily track and categorize green chemistry principles and associated teaching practices as a novel and valuable area of chemistry PCK.

The Resource Folios Approach to Pedagogical Content Knowledge

For this project, I use the methodology of Resource Folios as developed by Bernard Loughran and his colleagues to help teachers formulate their PCK and share that knowledge with others (Bertram & Loughran, 2012; Loughran, Berry, and Mulhall, 2012). This approach provides both a reasoning and a structure to studying PCK and has been used successfully in science education contexts.

In their pivotal text, Loughran et al. (2012) reviewed the work on PCK and critiqued some developments that have become counterproductive. They highlighted the tension between the generalizing thrust of research and the specificity inherent in the concept of PCK. "It seems as though the more that PCK is refined and/or redefined in a bid to make it more concrete, the less valuable it becomes as a descriptor of specialist or expert knowledge of practice" (p. x). Furthermore, an overly proscriptive approach to PCK risks omitting some factors that support good teaching. "Although it is important to have some routines in teaching, when teaching becomes 'routinized', elements of quality teaching (e.g. engagement, enjoyment and intellectual challenge) can be dramatically diminished; or worse, absent all together" (Loughran, Berry, and

Mulhall, 2012, p. 2). Therefore, PCK research needed some clarification to avoid overly concretizing or routinizing teaching practice.

Loughran et al. (2012) also argued that research on PCK has not been tailored to the practical goal of supporting teacher practice. As they explain (Loughran, Berry, and Mulhall, 2012),

> The manner in which research into PCK has been conducted has created an impasse for teachers. The research literature on PCK is certainly extensive; however, the outcomes of such research appear to speak more to educational researchers and other such academics than to teachers who surely are not only the producers of such knowledge, but also important end users… much time and energy was expended evaluating PCK as opposed to exploring concrete examples of how teachers teach particular content topics in particular ways that promote understanding. Therefore, unfortunately, PCK has not been developed through the research literature in ways that necessarily directly correlate with enhancing the practice of science teaching. (p. 11)

Some research on PCK became too theoretical and separated from classroom practice in a way that made it less meaningful.

The major value of PCK, then, is its role in clarifying teachers' and researchers' language about teacher practice. In other words, for PCK as a practical tool, "the value to teachers was in terms of encouraging reflection on practice, creating a shared language for discussing science teaching and learning, and offering insights into practice, all of which became a springboard for their own professional learning." (Loughran, Berry, and Mulhall, 2012, p. x). Developing teachers' PCK does not guarantee good teaching practice, but it does provide one additional touchpoint for teachers to develop with each other. Loughran et al. (2012) refocused PCK research on teacher practice because,

> Teachers are in fact producers, not just users, of sophisticated knowledge of teaching and learning. And, the complex ideas associated with exemplary practice are better able to be portrayed and shared in meaningful ways if labels and

> descriptors such as PCK are better understood and used. Therefore, a language that comprises aspects of professional practice is central to moving knowledge of practice out from the individual and into the professional community at large. For example, in many studies by teacher researchers, language (a shared vocabulary) has been central to the development and sharing of their sophisticated knowledge of practice. (p. 12)

This perspective should inform both research and interventions about teacher practice. "Consequently, through professional learning the need to better articulate one's own learning about practice encourages the development of a language for sharing such knowledge. One aspect of such language can be described in terms of pedagogical content knowledge" (Loughran, Berry, and Mulhall, 2012, p. 5). Importantly, other aspects of language, like content knowledge and pedagogical knowledge as distinct from PCK, can still contribute to teachers' professional learning.

Similar to other researchers, they noted that individual teachers naturally develop their own PCK. The goal of larger research projects then is that "important features of PCK need to be able to be recognized, described and articulated so that PCK can be developed and shared beyond the individual" (Loughran, Berry, and Mulhall, 2012, p. 13). The goal is to use the language of PCK to facilitate the transfer and development of teaching practice for more teachers.

One challenge in this research is that such a depth of engagement required in developing PCK for individual topics means sacrificing the breadth of topics normally covered in a class. "The dilemma, then, is that although students' conceptual understanding may well be richer, the amount of content covered is likely (at least, initially) to be much less than that which might normally be achieved" (Loughran, Berry, and Mulhall, 2012, p. 16). Teachers and researchers might need to be convinced of the long-term value of developing PCK to overcome the inertia of existing curricular structures.

The Structure of Resource Folios: CoRes and PaP-eRs

The Resource Folios approach includes two parallel structures for organizing and communicating PCK. The first structure is a Content Representation (CoRe) which is a table that delineates a teacher's knowledge and approach for certain content at their grade level. The second structure is a Pedagogical and Professional-experience Repertoire (PaP-eR) which provides a contextualized example of teacher practice for a given topic through a range of formats, like a syllabus, annotated lesson plan, or stylized interview. "PCK representations demonstrated through a CoRe (or in some cases CoRes…) and the associated PaP-eRs combine to create a Resource Folio of PCK on that given content/topic" (Loughran, Berry, and Mulhall, 2012, p. 17). These Folios can then be used in professional development for teachers, providing the common language to move research into practice.

Developing a CoRe can also be a professional development experience in itself for groups of teachers. "In our work with science teachers, we have consistently found that using a blank CoRe on a double sheet [abbreviated form reproduced below as Table 1] … is significant for helping participants to negotiate different regions of the CoRe and to move freely from one area to another as their ideas and thoughts progress" (Loughran, Berry, and Mulhall, 2012, p. 20). This structure helps prompt teacher reflection on their often unstated knowledge about teaching certain content. In these types of professional development experiences, "participants required an opportunity to work with a CoRe to develop a familiarity with the process in order to manage the demands inherent in completing the task" (Loughran, Berry, and Mulhall, 2012, p. 217).

Table 1. Adapted Version of a CoRe Worksheet. Each of the eight items would be considered for each Big Idea. Additional columns would be provided to cover 6-8 Big Ideas for a certain unit of content.

Grade Level and Topic for this CoRe	**Big Idea A**
Title or description of the big idea.	
What you intend students to learn about this idea.	
Why it is important for students to know this idea.	
What else you know about this idea that you do not intend students to know yet.	
Difficulties, limitations, or misconceptions connected with teaching this idea.	
Knowledge about students' thinking which influences your teaching about this idea.	
Other factors that influence your teaching of this idea.	
Teaching procedures (and particular reasons for using them to engage with this idea).	
Specific ways of ascertaining students' understanding or confusion around this idea.	

In contrast to the overarching perspective of CoRes, PaP-eRs present a contextualized story of how one teacher approaches the content. These examples help support teacher development because, "in many ways, teachers' stories actually carry most of the important information that helps other teachers to identify with, and therefore extract their own meaning from, a given description of a teaching and learning situation" (Loughran, Berry, and Mulhall, 2012, p. 16). It might seem counter-intuitive that a more specific example is more easily transferable, but the contextual information of a real class helps teachers to imagine the content in their own classroom.

There are significant challenges to developing Resource Folios for any content. For many teachers, “in reflecting upon one's own experiences of teaching and learning in science, it can sometimes be difficult to look back and see the changes in practice (and the reasons for those changes) that led to the manner in which one teaches at the present point in time” (Loughran, Berry, and Mulhall, 2012, p. 223). Researchers and facilitators still have a significant role to play in supporting and scaffolding this type of reflection with teachers, working together to construct accurate representations of PCK that can be shared with a wider community.

Teacher Change: Extending Constructivism to Teacher Training

PCK is grounded in the theory of teacher change as a focused area of education research. Rather than viewing in-service teachers as static or complete educators, the field of teacher change investigates how they continue to develop their teaching practices especially because of interventions or interactions with other teachers (Johnson & Fargo, 2010; Kaasila & Lauriala, 2010). For example, Johnson and Fargo (2010) studied a two-year professional development program for middle school science teachers and tracked teacher change across four variables, “(a) the design of the planned lesson, (b) the actual teacher implementation of the lesson, (c) the appropriateness of the science/mathematics content, and (d) the classroom culture and engagement of all students” (p. 14). They correlated classroom observations with student test scores on a standardized exam to understand how teacher change affects student achievement. Kaasila and Lauriala (2010) advocated for the complex role of sociocultural factors that influence teacher change. Like students, teachers are not all the same, so any teacher change argument must consider group differences.

These perspectives draw on the larger field of Constructivist literature which presumes that teachers and students are influenced by past beliefs and their social context, rather than being blank slates to learn new information (Marlowe & Page, 2005; Zehetmeier et al., 2015). As a broad category, this approach helps to situate teachers as learners, especially to study the adaptability of various levels of interaction with their peer teachers.

Within teacher change literature, the Lead Teacher Program best reflects the Train the Trainer model, which is an approach to professional development that trains leaders to bring skills to their own communities (Koerner et al., 2014; Weingarten et al., 2018). Empowering teacher leaders can impact a much wider community than direct professional development alone. This model offers the most relevant methodological grounding for the LTP, including research tools and best practices about improving the program itself and studying the impacts on the broader community.

Professional Learning Communities: A Model of Peer-Supported Growth

I also draw from a related approach to teacher change based around Professional Learning Communities. Interventions in this area generally form groups of peer teachers in a variety of structures to share periodically about their teaching practices (Lakshmanan et al., 2011; Sargent, 2014).

Specifically in environmental education, the framing of Communities of Practice has been used to study the way that teachers and communities shape educational environments beyond one-time professional development events (Denscombe, 2008). Teachers have been shown to improve their knowledge and attitudes through collaborative, hands-on field inquiry (Songergeld et al., 2014). The role of mentors has been highlighted as an influential feature of learning communities (Ernst & Erikson, 2018). Although not the model directly used in LTP, these intertwined perspectives on communities of teacher learners can contribute to our understanding of how groups of teachers influence each other and the social factors that can affect school cultures.

Diffusion of Innovations Theory: The Factors that Affect the Transfer of New Ideas

A sociological research perspective called Diffusion of Innovations Theory has also been applied to study the way educational innovations are shared (Borrego, Froyd, & Hall, 2010; Hung, Jamaludin, & Toh, 2015; Sargent, 2015; Rogers, 2003). Innovations include any idea that are perceived as novel by an individual or group. The landmark text by Everett Rogers (2003) describes five stages of the innovation-decision process “through which an individual (or other decision-making unit) passes from first knowledge of an innovation, to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision” (p. 170). These stages help to frame an individual’s experience of adopting or rejecting a new idea.

Many professional development programs for teachers can be understood as part of the diffusion of innovations process. New curricula or pedagogy can be spread through formal or informal networks. For example, Borrego et al. (2010) studied the diffusion of seven educational innovations in engineering departments across the US by surveying department chairs about their knowledge and adoption of the innovations. Hung et al. (2015) argued for apprenticeship and cluster models for teachers to support the adoption of educational innovations throughout

Singapore. Framing educational innovations through the perspective of diffusion can help to track curricula in a wide variety of contexts at local or international levels.

In a particularly interesting study, Sargent (2015) researched professional learning communities in China to understand the role that networks of teachers play in the diffusion of pedagogical innovations. This study highlighted both the role of “rigorously selected teacher leaders [who] are given access to special training and networking opportunities” as well as “ample and varied opportunities for teacher interaction in teacher professional learning communities within the school [which] allow for the diffusion of innovative ideas among teachers, whose shared experience and understandings make it easier for mutual learning to occur” (p. 127). The innovations were spread through “opinion leaders [who] are those members of a social system who are more exposed to external communications, more cosmopolite, enjoy a higher social status, have a unique and influential position in the system’s communication structure, and are at the center of interpersonal communication networks” (pp. 109-110). Similar to Train the Trainer models, teacher leaders in this context played a pivotal role in spreading educational innovations and are an appropriate focus for research.

In summary, these perspectives provide a basis for studying LTP as an innovative educational community for teachers to develop and share their PCK. Chapter 4 draws from these areas to explain the methodology and methods of this project.

CHAPTER 4

METHODOLOGY AND METHODS

"We are part of the world we study and the data we collect. We construct *our grounded theories through our past and present involvements and interactions with people, perspectives, and research practices." –Kathy Charmaz in* Constructing Grounded Theory (2014)

Against the backdrop of the theory surrounding green chemistry and the research background about teacher training, the rest of this project will focus on LTP as a focused case study that holds much wider implications for the chemistry education community. The main research questions for this project are:

1) How does PCK transfer and transform between K-12 teachers in an empowering, peer-led, green chemistry education focused community?
2) What effects does teacher empowerment have on their classroom teaching practices and PCK?
3) Which organized program activities and other community interactions support teachers' sharing and development of PCK?

The project's methods (Chapter 4) and results (Chapter 5) are discussed as they relate to answering these main questions.

Grounded Theory Methodology

This work largely drew from the qualitative and sociological approach of ground theory as the most appropriate methodology for our research goals. Charmaz (2014) gives this description: "grounded theory methods consist of systematic, yet flexible guidelines for collecting and analyzing qualitative data to construct theories 'grounded' in the data themselves"

(p. 2). Researchers in grounded theory recognize the role of the researcher and attempt to acknowledge and critically analyze potential bias as a natural part of the research process (Harry, Sturgis, & Klingner, 2005). The methodology of grounded theory guided decisions about research procedures in an iterative process among the research team, with input from other researchers and program participants.

Because LTP and green chemistry are in early stages of implementation, an exploratory and descriptive approach like grounded theory offers a clear structure for data collection and analysis. Researchers in program evaluation methods also encourage developing a “program theory” in order to form a “conceptual framework linking the interventions to program outcomes” (Posavec, 2011, p. 45). Through grounded theory, the research goals focused on helping articulate program goals and participants’ understandings of green chemistry to construct a rich, descriptive and foundational theory of K-12 green chemistry that can be used by later researchers and program organizers to advance the field further.

Approval and Privacy Protocols

The research project was officially approved by LUC’s Institutional Review Board on September 30, 2020 as posing minimal risks to research participants (project #3028). All members of the research team completed research ethics training within the last three years as required by LUC. Written consent was obtained for all participants, including the option to allow the use of their full name, an option for confidential participation with a pseudonym and restricted identifiable details, or minimal participation where no direct quotes or data would be included in publications. A sample consent form detailing the project is included in Appendix A. Because of the options provided around identifiable details, information like names or locations might be masked in subsequent sections to respect the privacy of the individuals involved. Details that might affect the substance of quotes, such as the context of a school, will be preserved or edited in a way that conveys the intended meaning as clearly as possible.

Because of the participatory nature of this work, it is also important to note that consent was treated as an ongoing conversation between researchers and participants. Drafts of results and plans were shared frequently with program staff and teachers in order to solicit feedback or clarification. This process both improves the quality of data as a secondary-check on researchers' interpretations as well as a trust-building practice among participants to foster transparent communication. Written consent forms were one level of privacy, understood within the context of larger conversations about the research project.

Interviews and Coding

The largest source of data came from twenty-eight phone interviews with current and former LTP participants. The interviews covered the entire sample set of current and former LTs as well as both program staff members. Especially with such a small program, this population sampling approach helps ensure that our data are representative of all the program participants. A semi-structured interview script (Appendix B) had been developed to cover participants' backgrounds, perceptions of the program, and self-reported classroom practices. The interviews were designed to elicit participants' self-understanding of the program and prompt reflection on any changes in their teaching theory and practice (Weiss, 1995). By working with participants to construct and clarify language about LTP, this interview approach provided a rich qualitative basis for shaping a program theory (Posavac, 2011).

Most interviews lasted between thirty and sixty minutes, and all were conducted by the primary researcher who took written notes of main points emerging from each interview. To ensure accurate quotes and facilitate deeper research, the interviews were audio-recorded and digitally transcribed. The research team, including three undergraduate researchers, made initial edits of the transcripts. Then pairs of researchers independently read through assigned transcripts, noting themes and developing coding categories. These pairs would then create a consensus coding scheme for the transcript, discussing any discrepancies between their codes to reach a common understanding (Harry, Sturgis, & Klingner, 2005). Throughout this process, weekly research meetings helped to clarify developing codes, including written memos and an ongoing code list. The themes were divided into two broad categories: a priori themes (Table 2) that identified initial areas of research interest and grounded themes (Table 3) that developed a grounded theory of the interview data (Charmaz, 2014; Miles & Huberman, 1994).

Table 2. A Priori Themes from Interview Transcripts

Code	Title	Theme Description
GDEF	Green Chemistry Definition	A definition or description of green chemistry
PDIF	Diffusion of PCK	Ways that LTP participants share knowledge with other people
LDES	Description of LTP	Description or pitch for LTP, what it is, on-going activities
SUCC	LTP Successes	What participants think has worked well for LTP and should be maintained, one time examples
IMPR	LTP Improvement	What participants think could be improved or changed about LTP
CERT	Certified Lead Teachers	Any description of what a “certified” or “alumni” teacher role might look like after the three years of LTP
CLEX	Classroom Example	Classroom example of how a teacher approaches green chemistry, potential case studies, not general teaching strategies

Table 3. Grounded Themes from Interview Transcripts

Code	Title	Theme Description
GCAC	Green Chemistry as Chemistry	Any description along the lines of "we shouldn't call it 'green chemistry.' It should just be 'chemistry.'" Rebranding as sustainability or extending out to other classes
PROF	Professionalism	Times when LTs describe being treated as professionals or having an audience in LTP specifically, not programs before or outside the program
RECR	Recruitment	How teachers were recruited or got involved with LTP or BB
MOTI	Motivation	Teacher's personal motivation to join LTP, what they were looking for from the program
JUST	Justification	A participant explains why green chemistry is important, what it fixes, or how it impacts the world, specifically in education
REGI	Regional Connections	Place-based examples of the local environment involved in teacher's classrooms

All coded transcripts were uploaded into NVivo 12 for further analysis. The research team then worked collaboratively to refine and describe the codes. At this stage, several versions of initial research were shared with research participants to solicit feedback and check for any major oversights in the areas covered. Chapter 5 covers the results of this process in more depth.

Classroom Observations

Because of the distinction between planned and enacted PCK (Aydeniz & Kirbulut, 2014), it was important for us to investigate teachers' practice of green chemistry along with their self-described understanding. Originally, the research plan included in person classroom observations for six program participants as well as six control teachers over the two years of data collection. Because most of the teachers moved to online instruction, this plan had to be revised. Two teachers were observed in-person for half a day each in the Spring of 2021. These observations served as a pilot to consider future work. In Fall of 2021, the primary researcher coordinated with three additional teachers to observe a series of class periods virtually. Letters of cooperation (Appendix C) were coordinated with each school, and a message for parents (Appendix D) was shared through each of these teachers as approved in the IRB protocol. Field notes and audio recordings were taken for each observation and focused on the teacher's enacted PCK as related to green chemistry. The five areas of PCK provided the initial categories for these observations, namely the teacher's understanding of (1) orientations toward science, (2) science curriculum, (3) students' understanding, (4) assessment, and (5) instructional strategies (see Magnusson et al., 1999, p. 97). Transcriptions of the recorded audio helped provide a basis for quotes and organizing these observations. The observations were mainly developed into textured examples of PaP-eRs to illustrate green chemistry PCK in action (Loughran et al., 2012), which are included in Chapter 5.

Field Notes and Content Representations

The final source of data included field notes of various LTP activities, including several group video calls, two Summit events in the summers, and some online webinars conducted by teachers and program staff. Notes from these events helped to track the wider impact of the program and the variety of ways that teachers share PCK. Field notes draw from a grounded theory approach where themes are developed from the language of program participants in addition to the interviews (Charmaz, 2014; Emerson, Fretz, and Shaw, 2011; Weiss, 1995). By actively participating in these events, our research also helped shape program activities and provide the direct benefit of an outsider perspective for the staff and teachers. The reflective process involved in field notes supported larger program reflection and flexibility when methods needed to be adapted to respond to a program in development.

Additionally, the Resource Folio approach provided another method of investigating teacher's espoused PCK (Loughran et al., 2012). Before the LTP Summit from July 20-22 of 2020, each teacher was asked to work on a Content Representation (CoRe) worksheet, which prompted them to describe their classroom practices for specific content. See Appendix E for a blank CoRe worksheet. This method is designed to make explicit the often implicit knowledge that teachers have about PCK. It provides a common structure and language for teachers to share their teaching expertise with each other and with a wider community. At the Summit, one session was reserved for teachers of similar content areas to talk about their initial CoRe. These conversations and the worksheets helped shape interview questions and later research plans.

Limitations and Adaptations

Although qualitative methods provided the most appropriate approach for the goals of this project, the research design had some limitations. This project had a limited scope of 28 educators directly involved in LTP, which means that conclusions are influenced by the highly self-selected nature of this group. Observing activities with wider groups of participants like webinars helped to expand our understanding of the diffusion of PCK among more diverse teachers. LTP and many of the teachers identified their focus as green chemistry, which is not a widely practiced area of high school science education. Although I am focusing on this green chemistry component, many of my conclusions can still apply to other communities of K-12 educators, especially in the sciences. I echo other education researchers like David Sobel, in arguing "that my goal is not to advocate for one particular model, but rather to provide the ethnographic particularities that illustrate how the process has worked in a variety of places" (2013, p. 61).

Working with a research team and conducting participatory research also brought unique challenges. This type of work is inherently social and less-defined up front, requiring ongoing communication and updating methodology to respond to the context. Researcher bias can pose significant challenges for qualitative research, but also an outsider perspective can provide benefits for a program to help analyze their own biases and blind spots (Posavec, 2011). Because LTP participants and staff are highly-engaged professionals, their perspectives were important to incorporate as active voices in the research rather than distant data to be passively observed. Consistent meetings with program staff, sharing drafts with research participants, and sustained contact with program activities all helped to control for outside bias and refine research conclusions.

There were inherent programmatic challenges which prompted several changes to the project. One challenge is that many of the qualities which make LTP unique (small number of participants, wide variety of activities, and influential partnerships with state and national organizations) also make it difficult to study and name principles that are transferable to other training programs. This highlights the importance of a mixed methods approach to capture these dimensions of the project in more of a coherent whole with rich descriptions that allow other researchers and educators to decide what might work in their own context. The focus on PCK through CoRes and PaP-eRs helps capture a lot of the teachers' experience, but it does not include all the activities that LTs are involved with. Triangulating data collection through interviews, classroom observations, and programmatic field notes also helped to account for methodological biases in any one of these categories, even while the coded interview transcripts served as the major data source.

Because of the COVID-19 pandemic the past two years, most of the teachers have been teaching virtually much of the time and dealing with additional stressors on their classrooms. Naturally, that has meant changes in their teaching practice that do not reflect their typical approach and cannot be seen as representative of their PCK. Travel restrictions also meant that I could not visit classrooms as I had planned previously, so I focused on the methods I could use virtually. None of these challenges derailed the project, although some plans had to shift. In fact, the shifts revealed additional strengths in the adaptability of the LTs and the whole program design that are discussed further in chapter 5.

Qualitative, Descriptive, and Participatory Approach

Our overall choice of methods was based on both the goals of LTP and the research questions. The methods were largely qualitative and descriptive for several reasons. First is that the program is in a relatively early stage of its development, having been started in 2016. As such, program staff and participants are still shaping how the program works. Second is that the area of green chemistry, especially at the K-12 level is not well-defined yet, so initial research is needed to define the scope and goals of the field before more quantitative studies can be completed. Third is the wide diversity of schools with Lead Teachers across the US and Canada, posing significant challenges to make meaningful comparisons across contexts. Developing a common language through qualitative and descriptive research methods provided the most important data for improving the program and sharing results with a wider community. Our work was more about crafting program theory than evaluating against existing standards.

Although the ultimate goal of most education programs is the impact on students, our work focused largely on the teachers and programmatic connections. LTP shares this aspiration to impact students but aims its programming toward teacher leaders who can foster community and share expertise around green chemistry with other interested educators.

CHAPTER 5

RESULTS AND PROGRAM EVALUATION

"There is more art than science in the conduct of research on a topic as complex as the one we tackled. That art includes theoretical sensitivity to emerging data, which guides decisions about further data collection and ways to test emerging theory; interpersonal skill in the creation of a balance between rapport and appropriate distance with research participants; and self-awareness that allows for a critical view of one's own role in the research." –Beth Harry, Keith M. Sturges, and Janette K. Klingner in "Mapping the Process: An Exemplar of Process and Challenge in Grounded Theory Analysis" (2005)

The qualitative coding process used in this project helped to explore the complex social systems connected to LTP. The results in this chapter are presented in a linear way that seeks to build a grounded theory about green chemistry from the perspective of program participants. Representative quotes bring these categories into sharper focus and serve as a reminder that the participants' expertise is the primary data source. First, I begin with an overall program evaluation for LTP before considering wider theoretical implications for the field of K-12 green chemistry education.

A Program Pitch

In order to evaluate a program, a clear description of program activities and goals is needed as a basis for any qualitative comparisons. Currently in its sixth year, LTP remains flexible in its programming with several key features that have remained consistent. The primary activities for participants include: writing curriculum that is hosted on the Beyond Benign website, presenting sessions to pre-service teachers through several college programs, running online webinars for current teachers in partnership with state agencies or other non-profits, writing articles or giving presentations in professional conferences, and engaging in supportive relationships with other teachers especially in their geographic region. All these activities help Lead Teachers share and translate their PCK to others.

Throughout the interviews a need became clear for a standard elevator pitch for the LTP based in the teachers' perspectives. I began asking each participant about how they would describe the program to another teacher and was surprised both by the difficulty of that question for some teachers and the diversity of their responses. Although they were participating in the same program, their descriptions may have reflected different grade levels, social locations, or years of experience with green chemistry. Based on the interviews, a synthesized pitch for LTP is:

> The Lead Teacher Program is a unique educational opportunity for active teachers across the United States and Canada. The overall mission is to promote green chemistry, and along the way, these teachers have managed to create a supportive, empowering, and passionate community that enhances their innovation and confidence. Teachers often collaborate to increase green chemistry's educational outreach and impact by communicating why and how green chemistry matters to other educators or students, including those not interested in science. Throughout the 3-year commitment, Lead Teachers undergo training with a free, online curriculum that can be easily adapted to their students and state requirements and use their individual skillset to contribute to the program (e.g., presenting at conferences, writing curriculum, etc.).

With this pitch, a program evaluation can begin to consider how LTP succeeds and how it can improve its activities to better support these goals.

Sharing and Building Pedagogical Content Knowledge

In addition to an internal understanding of green chemistry, I was interested in how teachers share their PCK about green chemistry with each other and wider communities, a process that I call "diffusion." Because this expertise is often implicit (Loughran, Berry, and Mulhall, 2012), it was important to understand how LTP affects the diffusion process and how other programs might benefit from a similar approach. Rather than fostering PCK development directly as I initially expected, many of the LTP activities focus on sharing information between teachers. As one of the program staff reminds the teachers at each monthly call, the program goals are to:

1) Empower others to implement Green Chemistry in the classroom
2) Equip other educators by sharing Green Chemistry resources
3) Create Beyond Benign materials

These goals serve as guiding principles for the staff and teachers as well as potential evaluation metrics.

Participants in LTP are experienced teachers, many having taught for over 15 years and engaging deeply in other professional development work. My conversations with teachers have also helped to illustrate how they achieve the program goals. Their primary activities include: writing curriculum that is hosted mainly on the Beyond Benign website, presenting sessions to pre-service teachers through several college programs, running online webinars for current teachers in partnership with state agencies or other non-profits, writing articles or giving presentations in professional conferences, and engaging in supportive relationships with other teachers especially in their geographic region. All these activities help teachers share and translate their PCK to others.

Beyond Benign facilitates relationships with other organizations and government agencies such as state departments of health to promote and fund programs. Several universities have partnered with Beyond Benign to offer training and certificates in green chemistry for teachers. These types of partnerships highlight a major benefit to the program as a result of Beyond Benign’s reputation within the chemistry and educational communities.

Recruitment and Motivation of Lead Teachers

The LTs themselves were recruited or drawn to LTP in a variety of ways that suggest insights into program activities and future recruitment. The primary way that teachers got connected was through participating in the educational outreach offered by Beyond Benign such as workshops or webinars. A typical story would be that a teacher participated in a workshop, then reached out to Beyond Benign for more information, and was invited to apply to LTP. Sometimes teachers were connected through colleagues such as this teacher who explained:

> I got connected through one of my fellow teachers, a technology teacher. He actually used some of the curriculum that they produced early on, and I participated with him in doing something with science and technology together. A couple years later, I think about three or four years later, they reached out to a bunch of teachers that actually had demoed their curriculum, and they asked if I was interested in participating in a new project to write some curriculum, and then since that happened, I was connected with Kate Anderson. She then... invited me to participate in the Lead Teacher Program the following year, so that's how I got into the program.

A few teachers found videos or curriculum online that initially interested them and led to them reaching out to Beyond Benign. One teacher mentioned that watching videos of Dr. John Warner was the first connection to green chemistry and then to Beyond Benign and LTP. Overall, the wide net of activities and resources from Beyond Benign helps to reach a large audience, including many K-12 educators. Then, teachers who have an initial interest often initiate some contact and are invited by program staff to apply to LTP specifically.

Participants also described their personal motivations for initially getting involved with LTP. Most of these motivations for joining could be summarized as (1) further integrating sustainable principles into science education, (2) making a larger impact on the field of science education, and (3) collaborating with a community of like-minded teachers. The most frequent motivation was teachers' interest in environmental or sustainable practices, which they found were expressed through LTP. One teacher explained, “I am passionate about the environment, and that's part of who I am.” They often noted their pre-existing passion or interest in sustainable science as a motivation to join the program. A second motivation for many teachers was the potential impact they could have on students or the field of science education. One teacher said, “it's all about trying to save the world and become more sustainable through science and trying to get more people to become scientists or, even better, science educators.” Finally, several teachers explained the appeal of collaborating with other teachers. One teacher put it this way: “I'm really excited just to be surrounded by people that really have a very strong content understanding besides me... being around a group of people that really have this common cause, who tend to go together.” The collaboration in LTP offered something that teachers were missing in their other professional communities.

Main Successes

In the interviews, the most frequently cited benefit of the program was the collaborative and supportive community. Participants referred to the personal interactions fostered between LTs through friendships, regional team projects, mentoring relationships, and digital connections. There were particular benefits of the geographic diversity of program participants and the common passion shared between the teachers. As one teacher explained:

> The advantage is that you get to meet other people. You get to share ideas... I get to listen to people from all over the country and then bring those ideas back to [my school] or share our ideas… and send them out. So, it’s a great collaboration between people who are all very passionate about a topic.

In contrast to the isolation that some teachers might feel as the only chemistry or science teacher in their school or district, the Lead Teacher Program provides a sense of belonging outside of a limited geographic region. Teachers emphasized the way the community was constructed, like one participant who said, “Beyond Benign fosters this community and this connection. And it’s just a supportive environment; it's not judgmental." Clearly, the program activities provided many of these teachers with a shared feeling of community.

Several teachers described the impact of LTP on their teaching approach. On one level, teachers described changing their own practices and materials in their classrooms. One teacher recalled "looking at the curriculum that I teach and then also initially, the materials that I was using and how I could adapt that with the principles of green chemistry." The teachers found support and inspiration to consider their classroom practices in light of green chemistry. Another teacher mentioned feeling "reinvigorated in teaching" through participating in the program. On another level, some teachers noted shifting to teach these principles to students directly as a result of their work in LTP. One teacher stated, "I think being in the Lead Teacher Program has gotten me more upfront about teaching green chemistry to my kids as a thing, as an idea, rather than just doing the behind-the-scenes stuff." The shift from "behind-the-scenes" pedagogical inspiration to "upfront" work with students was echoed by several other teachers as a unique impact of LTP.

Another frequently-mentioned success was that participants felt treated as professionals throughout LTP. Sometimes they cited the opportunity to have a wider audience or to impact a larger group of people. One teacher spoke passionately that through LTP:

> You have the opportunity to impact not just your students, but you have an opportunity to impact the students of other chemistry teachers, and so you can greatly increase your own impact on sustainability and on the principles of green chemistry for a much larger number of people.

One of the program staff members spoke about their intentionality with providing these opportunities, saying, "I think our strength is making sure that we elevate [program participants] because… the program doesn't turn these teachers into exceptional teachers. They come in as exceptional teachers and then we open other doors for them." Similarly, teachers felt respected and empowered by program staff through receiving a stipend for their work, having travel arranged for conferences, and receiving clear details and resources for other events. These ideas came up so often that our team felt it warranted a specific code. One reason for this frequency could be that K-12 teachers do not engage as regularly in scholarly activities as higher education professionals. Lead Teachers seek out and engage with these opportunities more directly and expressed appreciation for them. This professionalism theme highlights the unique benefits of the LTP, beyond content and connections with other teachers.

Certain program activities were highlighted in the interviews as having more of an impact on teachers. A highlight of the program for many past participants was the summer summit, where participants from each of the three years would gather in Boston. When asked about what makes the program successful, a participant immediately named “the Lead Teacher Summit, the one where Beyond Benign really gives us kind of like the hands-on approach that most teachers need to be able to experience and do, which makes it easier to incorporate into their own practice.” Other teachers emphasized the value of trying out labs at the Summit with other teachers to share any insights from a variety of classrooms. This type of sharing is a direct exchange of PCK, and the teachers often noted its impact on their own teaching, even in widely varying contexts. The success of the Summit even translated to a virtual format for many of the teachers the past two years and was still cited as an important program activity.

Several teachers highlighted the importance of the program focusing on participants who are actively teaching in K-12 classrooms. The teachers felt better able to connect with and learn from peer teachers who know the current context of teaching. As one participant said, “it’s a more valid discussion as opposed to that person who hasn’t taught for twenty years who’s just a consultant somewhere.” The value of having current teachers in the program included both sharing with peers and having the opportunity to try out activities in their own classrooms. Beyond Benign can provide structured programs and curriculum, but peer teachers are better able to provide the pedagogical insights that come from active classroom experience.

Overall, LTP succeeds at fostering a supportive and collaborative community of current teachers who are interested in developing their practice of green chemistry in K-12 education. Participants appreciate feeling treated as professionals and having opportunities like the summer summit to share experiences and hear advice from other teachers. The interviews helped to explore these main successes and to suggest some potential areas for improvement.

Potential Improvements

In the interviews, teachers were asked directly about improvements or changes they would make to LTP including activities to do more, less, or differently. Their answers varied much more than the successes, were more difficult to categorize, and sometimes directly conflicted with each other. However, some potential improvements are listed here along with representative quotes to give a fuller picture of the program.

Some teachers expressed a desire for more direct program structure like being invited by staff for specific projects. However, other teachers appreciated and desired more freedom to choose their own activities to share about green chemistry. Because these teachers are all working at least full-time, many of them also identified the time strain of trying to do additional work through LTP. One teacher said, “it’s sometimes challenging to be able to meet those deadlines and those commitments with the other things that we have going on.” The program staff deal with these issues in part by working around the rhythms of typical school schedules, with more work over the summer or around breaks. That flexibility allows teachers to work on projects when they have the most time but also poses challenges for program structure and collaboration between teachers who may be on different schedules.

Given their limited time, teachers also wondered about which program activities were having the most impact and how energy might be focused on those. One teacher paired the idea of limited time and questions about program activities, saying, “I always felt guilty like I’m not connected enough, or like I’m like not doing enough, but I also think that throughout the program itself, it was something that was hard to figure out what the best way to do it, how to do this really well.” Many teachers seemed unsure about how to make the most of the time they dedicate to program activities. One participant talked about trying to follow up with people who participate in webinars and workshops, partly to decide which of these activities have the largest and longest-term impact.

Some teachers had suggestions about improving the recruitment of teachers, specifically about which kind of teachers should be included. Sometimes the desire was simply to involve more teachers in the program from more school districts and communities. Another common desire was for teachers to be recruited from similar geographic regions. Teachers who had another Lead Teacher in their region mentioned the value of that collaboration since they understood the local context and expectations. Several teachers suggested that the program staff could actively seek out pairs or groups of teachers from similar regions to foster those kinds of connections. One teacher described a feeling of isolation and the desire for a regional peer:

> I felt alone a lot of the time because I was the only person in my region, so when something would come up, or something local would come up, I had to go by myself, which was fine, but many other Lead Teachers have kind of paired up. So you have two in close districts, and two in driving distance, something like that. So it would be nice if they could recruit… two [participants] that are close by one another.

Other teachers suggested including more elementary school teachers since the program has been heavily skewed toward middle and high school teachers. One teacher mentioned including people of different age ranges in the cohorts as another dimension of diversity. A few teachers also appreciated a recent focus on environmental and racial justice work, which could also suggest a focus on recruiting more teachers of color or teachers who have specific interests in continuing that part of the program.

A large area for improvements dealt with the time frame for LTP. In the interviews, teachers often expressed frustration with completing the three-year commitment without accomplishing their program goals. One teacher said, "it's sort of like having the President of the United States, who once they start getting their idea out, they're out of time." Although program staff expect significant experience and preparedness to accept teachers into the program, many participants felt that it took them more time in the program to feel that they could accomplish goals like presenting a workshop or developing curriculum. Currently, teachers commit to the three-year program before transitioning to an "alumni" or "Certified Lead Teacher" role. Because program staff are still developing expectations for this role, the interview included a direct question to elicit participants' ideas, which could help shape the future of the program and remains an open area for improvement.

After the Program: Certified Lead Teachers

When asked specifically about the Certified Lead Teacher role, participants described potential activities such as mentorship, consultation on curricula, or regional recruitment work. Some teachers expressed their personal interest in maintaining a connection with the community of Lead Teachers. One teacher said, "I would want to stay connected to the group... especially in the local area or at least in the state area, that provides additional support." Because a supportive community was the most frequent benefit of the program, it seems consistent that teachers would want to maintain that support as much as possible after the three year commitment. A few teachers connected the interest in staying involved with the need of mentors for current program participants. One teacher gave this suggestion:

> I like the idea of some kind of mentorship program, but I feel like that can sort of occur within the current Lead Teacher cohort. Because you do have such a blend. It sort of depends on how many teachers stay and how many within a current cohort are established teachers... If there is a set of newbies and established educators in green chemistry within the current cohort, you can have sort of like a mentorship pair up, but if that's not the case, then I think bringing in past Lead Teachers… like 'you're partnered up with this person. Chat a couple times a year.' It doesn't have to be a huge thing.

Teachers had different visions for how a mentorship program might work, but many shared this desire to stay involved and a willingness to offer their support even after their formal program participation ends. Some teachers also expressed specific desires to stay involved with writing curriculum or facilitating webinars and workshops based on their schedule and personal interests.

Expectations for this role differed between program staff and participants, which reveals a significant area for consideration in future activities. Program staff expressed a desire for participants to become "ambassadors" who would seek out opportunities to share about green chemistry. The staff saw their role as supporting and encouraging these teachers, specifically "making people feel important… and telling them that with words… being more explicit about how much change they're making and how they're really the backbone of the program." Their hope was that the three-year program empowers teachers to be mostly independent change agents for the green chemistry education community. However, teachers often expressed wanting Beyond Benign staff to actively connect them with other organizations and opportunities, even after they left the program. Some teachers expressed hesitance about seeking their own audiences or feeling enabled to give presentations without the explicit invitation from Beyond Benign. This tension between the staff's desire to empower teachers and the teachers desire for support from the staff represents a significant challenge for developing the Certified Lead Teacher role.

Summary and Program Considerations

Overall, the Lead Teacher Program provides a supportive community to current K-12 teachers to develop curriculum and share their expertise about green chemistry with wider audiences. Participants benefit from interactions with peer teachers who are actively implementing green chemistry principles in their classrooms to develop their pedagogical practice. The program duration and structure were often cited as potential program improvements, including developing the role of Certified Lead Teachers who have finished the three-year commitment. The interviews with teachers helped to form this overview of program activities as a basis for reflection for program staff and participants.

CHAPTER 6

DISCUSSION AND IMPLICATIONS

"A language that comprises aspects of professional practice is central to moving knowledge of practice out from the individual and into the professional community at large." –Jeffrey John Loughran, Amanda Berry, and Pamela Joy Mulhall in Understanding and Developing Science Teachers' Pedagogical Content Knowledge, Second Edition (2012)

The Field of K-12 Green Chemistry Education

Apart from programmatic considerations, participants also described the broader field of green chemistry especially in K-12 educational settings. The green chemistry expertise within LTP as exemplified in the CoRe worksheets and extensive presentations by the participants could be shared more widely if it were systemized similar to other areas of PCK to form an initial understanding of how green chemistry functions in K-12 classrooms. Following Loughran, Berry, and Mulhall (2012), I use the interviews with teachers and the classroom observations to construct an initial Content Representation (CoRe) for green chemistry in K-12 education in this chapter. First, I sketch out several additional themes from interview quotes to explore participants' understandings of green chemistry.

Definition.

A major motivation for this project is that green chemistry has not been well studied or defined in education. The twelve principles lend themselves well to industrial and research contexts (Anastas and Eghbali, 2010) but not as easily to K-12 classrooms (Haack and Hutchinson, 2016). Teachers in LTP have direct experience in adapting green chemistry to their classrooms and with other teachers. Like other areas of PCK, this information is often implicit until directly assessed (Loughran, Berry, and Mulhall, 2012).

To investigate this area of expertise, the interview script asked participants directly to define green chemistry as they understand it in their classroom. Based on interview data, here is our working definition as a synthesis of participants' descriptions:

> Green chemistry is practicing sustainability; it is a healthier, safer, and more cost-effective approach to studying chemistry. It is a lens that allows for the understanding that sustainability at all levels can change our surroundings. As a worldview, it demonstrates the need to shift towards safer production methods, ultimately reducing waste and toxicity in the environment.

Some teachers described green chemistry with a more industrial or manufacturing understanding, such as one participant who said, "green chemistry is a way of making stuff safely and smartly, a way that improves everyone's lives without messing with your own health or negatively impacting others that you don't necessarily think about. It's the safest and smartest way to make stuff to help improve the world." Many teachers retained some connection with the manufacturing roots of green chemistry and convey that message to students.

Other teachers described green chemistry in terms of the educational benefits it brings, such as "emphasizing that chemistry doesn't need to be taught using things that make explosions, that uses chemicals that have higher risk, whether it's reactivity, flammability, things like that, but it can be done in a safe way and actually... when you use materials that are more benign, kids are typically more familiar with them and can make better connections to the concepts we're trying to teach anyway." For many teachers, green chemistry necessarily included these types of connections to students' lives.

The variety of descriptions from these teachers helps form a basis for an educational understanding of green chemistry. This type of description can help support the program goals of empowering and equipping other teachers to implement green chemistry. However, the diverse ways of defining green chemistry also imply a need for making these teachers' PCK more explicit to share with wider audiences. The CoRe worksheets will be an additional source of data to understand how green chemistry is incorporated to these teachers' classrooms and share that information more widely.

Justification.

A related theme included the justifications that teachers use for including green chemistry in their classrooms. Teachers often have to make the case to administrators or other teachers for taking on the atypical approach of green chemistry, so they have developed clear reasoning and evidence for their justifications. Beyond a definition, this code captured several common reasons that teachers cite for using this approach with their students, ranging from educational benefits to moral commitments to life skills that students develop.

A large set of justifications covered the educational benefits of green chemistry. Teachers noted many observations from their own classrooms involving student motivation and learning which confirmed their teaching approach. One teacher understood their classroom in this way:

> And having made that switch [to be 'more hands-on'] what a teacher always fears are accidents in the classroom and so you tend to do many demonstrations with students. And of course, if the students don't understand you kind of give them the answer. But having the green chemistry part and having students take ownership of it... it actually opens up a whole spectrum for these students.

This teacher highlighted both the paired benefits of allowing students to be "more hands-on" and to take more "ownership" of their work in the classroom, which allowed students more freedom for inquiry in a lab, pursuing questions that interested them within a safe context as guided by their teacher. Green chemistry is not the only educational approach that includes these types of goals. However, for teachers in LTP, green chemistry seemed to answer many of their wider questions about modern science education, which became a powerful justification for taking that approach.

Several teachers spoke passionately about their moral commitment to green chemistry and sustainable science education. As one of them explained:

> It's the only way that we can kind of save this planet, and I think that it's exciting for kids. It's empowering for kids, and it's a different way of thinking about things. And we have to change the way we think about things.

These teachers viewed science education as part of their broader commitment to the planet and to their students. For them, green chemistry is a vital tool for addressing environmental issues and, therefore, imperative to prepare “conscious citizens and not just scientists.”

Teachers also explained the benefits of green chemistry to foster life skills that extend beyond their classrooms. Collaboration was a key skill that one teacher highlighted by saying, “We want our students to be scientifically literate once they’re out in the community. But if they can't collaborate well together, that's not going to change anything.” Another teacher extended some of the twelve principles of green chemistry into life skills beyond chemistry, saying:

> I had students going on and not only going into chemistry, which I was excited for, but if they were going into any other field, they're taking those skills with them and they’re really branching out and again, utilizing those skills that they're learning, whether it be as simple as waste reduction or toxicity, or you name it, any principle that we're really looking at.

The ethical framework embedded in green chemistry offered these teachers something different than other science curricula. In the interviews, these justifications built upon the motivations to explain why participants stayed involved in LTP and continued using green chemistry principles in their classroom beyond their initial interest.

Green Chemistry as Chemistry.

Another common theme was that green chemistry could be described more broadly as simply chemistry or sustainability. One teacher expressed his hope for the future, saying, “I want to go to a big conference and do a workshop and not have to say it's ‘green.’” Many teachers shared this sentiment that all chemistry should be done in a green way to such an extent that the entire field of chemistry is replaced or reconsidered. Some teachers, especially at younger grade levels, extended this understanding to science education more generally and argued for the use of the term “sustainability” instead of “green chemistry.” One teacher said, “the term I like to use with my students is it’s ‘kind by design.’” Another teacher explained further:

> You don't have to be a chemist to implement green chemistry. [Teachers] don’t have to be teaching chemistry to implement green chemistry. Let's think about the sustainable practices or changing the name slightly so you feel more comfortable with that implementation in the classroom, but outside of more teaching pedagogy and just general outreach to some younger grades or younger teachers as well.

These teachers struggled to decide on the best language for their collective classroom approach, but green chemistry served as a common entry point or hook for all of them.

For these teachers, green chemistry added to and supported their existing approach to science education. One of the teachers gave this definition: “Green chemistry really is chemistry but done in a more thoughtful manner with the health and safety of not just your students but the environment at the forefront.” For some teachers, green chemistry became the predominant lens through which they saw and described their own teaching practice, such as one teacher who said, “Green chemistry can be found in every single unit that I do.” Another teacher added that they had been using green chemistry even before using the term, explaining, “as an elementary teacher, I’ve always done sustainable science, and we always do green chemistry. Everything in elementary is kitchen science.” Their efforts to translate this commitment to other teachers seemed to require a reconsideration of their language and led to these distinctions around "sustainability" or "green chemistry" simply as "chemistry."

Barriers to Implementation.

In reviewing the interview transcripts, our research team was surprised by one category of concerns that teachers noted which we describe as "barriers to implementation." These barriers go beyond directly programmatic concerns and speak to the field of green chemistry and the current state of K-12 science education both internally in a single classroom and externally between teachers and different communities. Therefore, these internal and external barriers can act as an entry-point to discuss how other areas of science education research might inform the broader development of environmentally-focused curricula.

The first recurring issue that teachers mentioned was the politicization of environmental topics like climate change or pollution. Several teachers noted the perception of their approach as "hippie chemistry" by other teachers, students, or community members. Sometimes this perception meant resistance or a lack of engagement with the classroom material. One teacher explained further:

> I've also found that people politicize climate change. Like the more libertarian or liberal teachers are going to do it... [but] more Trump train people are probably not going to do it, and I hate this because there are people that are on the Trump train that do believe in climate change. But there's a polarization there that I've always found hard to understand because the environment is the environment.

Other teachers echoed this frustration with trying to engage with topics in a scientific lens that are perceived and reacted to as political issues. Many of the teachers have developed strategies to anticipate these reactions, such as avoiding the word "green" or discussing the active role that manufacturers or businesses can play in responding to environmental changes. The challenge for these teachers is how to cover green or sustainable practices in science without the perception of pushing a political agenda and the associated resistance from students or colleagues.

In addition to potential resistance, some teachers expressed a concern that green chemistry comes across as shallow marketing or appeals mostly to peoples' emotions. One teacher described an apathetic response, saying, "if I talk about chemistry or green chemistry… the general public is just sort of glazy-eyed about that." Teachers sometimes found it difficult to engage with people who were not already bought in to the idea of green or sustainable practices. Another teacher expressed the need to better justify the purpose of green chemistry, arguing that currently "it's too much based upon 'feel good' and 'this is the right thing to do because we feel it's right.'" This concern highlights the alternate response of emotional interest in green chemistry that does not lead to deeper engagement. Teachers who want to engage with green chemistry have to contend with the emotionally-charged landscape of environmental and political issues.

A potential response would be to avoid potentially political topics altogether, but none of these teachers expressed that approach. In contrast, one teacher explained the importance of developing "informed, conscious citizens… because that's how all laws and decisions are made." The participants in LTP consistently addressed this tension between their desire to engage with political issues, knowing the types of challenges that such an approach might bring. The first barrier I want to highlight is this lack of a consistent and clear approach to these contentious political topics that get entangled with teaching green chemistry.

A second barrier is the time and adaptation necessary to integrate green chemistry into existing curricula and standards. As with any novel educational approach, there is inertia that teachers must confront to shift their classroom approach. One teacher explained their adoption of green chemistry in this way:

> I shifted my focus for my classroom away from the direct curriculum and more towards scientific literacy, an understanding of sustainability; How science, technology, engineering and math all merged together, and I just got a lot better at taking the lessons that I had and finding ways of twisting and incorporating.

Because green chemistry is more of a shift in perspective than content, it has the potential to be integrated into any classroom but also can be difficult to identify which practices constitute an authentic green chemistry approach. This shift to integrated science and interdisciplinary skills reflects a general trend such as the NGSS (2013), but it poses challenges to existing curricula. It requires extra work from teachers to adopt this innovative approach while still meeting existing school or state standards.

A third barrier involved issues with collaborating with other organizations or communities. Beyond Benign often facilitates connections with other groups through LTP, which is a large benefit to the program. At the same time, without significant program staff, these connections would be difficult for the average teacher to find or maintain. One teacher explained, “that seems to be a big direction we're going… partnering with outside organizations rather than just kind of advertising and talking about it, the concept of actually developing rapport with other people.” There is an inherently social dimension to the green chemistry approach, which engages local issues and communities. Forming these connections takes extra time and active engagement that many teachers do not have. Teachers suggested ideas like writing articles, collaborating with textbook companies, or even creating a podcast in order to share green chemistry with wider groups of people. These collaborative activities all involve other groups and reflect a major movement within green chemistry to engage real world issues.

A fourth barrier is the perception of chemistry as difficult or a higher level of science, especially compared with normal elementary curricula. Some elementary teachers mentioned that they hesitated to even get involved with green chemistry because of this perception. However, another teacher explained, “as an elementary teacher, I've always done sustainable science, and we always do green chemistry. Everything in elementary is kitchen science. We wouldn't have the harsh chemicals that the high school teacher would have.” As the field of green chemistry education is developed, having expectations based around grade levels could help teachers to understand and implement them better in addition to building skills across grade levels as more teachers implement green chemistry.

Pedagogical and Professional Experience Repertoires as Classroom Case Studies

During my conversations with teachers and in the classroom observations, I focused on potential case studies to include as Pedagogical and Professional-experience Repertoires (PaP-eRs, as identified by Loughran, Berry, and Mulhall, 2012). The goal of these case studies is to provide accessible examples to support teachers’ development of their own PCK. This work would answer one criticism of existing PCK research from Loughran, Berry, and Mulhall (2012), who argued:

> Much time and energy was expended evaluating PCK as opposed to exploring concrete examples of how teachers teach particular content topics in particular ways that promote understanding. Therefore, unfortunately, PCK has not been developed through the research literature in ways that necessarily directly correlate with enhancing the practice of science teaching.

Developing PaP-eRs based on these teachers’ stories is meant to help other teachers understand better what it means to integrate green chemistry into their PCK. To use a green chemistry metaphor, PaP-eRs act as catalysts that lower the activation barrier of teachers’ ability to imagine themselves implementing green chemistry. If used in pre-service teacher formation

(Demirdöğen, 2016; Aydeniz, 2014, Jong et al., 2005; Parga Lozano, 2015), PaP-eRs can illustrate parts of the reaction pathways of a teacher moving toward more sophisticated and explicit PCK around green chemistry principles. They can be used within LTP to support internal participant conversation or with outside groups to facilitate the diffusion and transformation of PCK between communities of teachers.

To accomplish these goals, four case studies are presented below with further commentary developed into a Content Representation (CoRe) for green chemistry in K-12 classrooms. I chose to present these PaP-eRs first to build our grounded theory starting from the classroom experiences of teachers before generalizing an overall CoRe. As Loughran, Berry, and Mulhall (2012) state:

> PaP-eRs bring the CoRe to life and shed new light on the complex nature of PCK. They help create ways to better understand and value the specialist knowledge, skills and ability of teachers thus making that which is so often tacit, explicit for others. (p. 25)

These case studies highlight the expertise of four exceptional teachers of green chemistry at the K-12 level.

Case 1: Teacher and Student Ownership for Safety.

In the interviews, teachers frequently mentioned the potential for green chemistry to encourage explicit conversations about safety in labs or when using any kinds of chemicals. Importantly for them, the responsibility for chemical safety includes both teachers and students.

In one of the interviews, a teacher described a full lesson to illustrate how green chemistry works on different levels between teachers and students to encourage ownership of safety in the classroom.

> One of my favorite things to do with Beyond Benign is... a types of reactions lab. Ultimately my curriculum said students have to be able to identify different types of reactions, and they should conduct experimentation with those different

reactions... They’re told they have to evaluate both of them using the 12 principles of green chemistry.

So one of those synthesis reactions will maybe be you have to heat things using the Bunsen burner. The other one you don't have to heat it, and so those two reactions they evaluate which one they're going to do, and they have to explain based on the 12 principles, which activity adheres best, or it’s either safest or occurs at an ambient temperature, or, you know, whichever one of the 12 principles it hits. Explain why, and then they do that for reaction type one, and then reaction type two, which is a decomposition reaction and then a single displacement. Then a double displacement. So, there are eight potential reactions, and they gotta pick which four they're going to do.

And they do that by researching the toxicity of the chemicals by looking at, you know, the waste products that may be produced by looking at the safety aspect of which ones do I have to use PPE for? Which ones do I only need safety glasses for? Which ones will I need gloves for? And also, which ones you’ve done at ambient temperature? Which ones have to be heated?

And they go through, and they pick the four that they're going to do, and then they justify them, and all of that is done in pre-lab, so that might be done in the period before the lab and then the next day they actually conduct the experiment where they do the four different experiments, they make their observations, they go through, they write the chemical reaction, they balance the chemical reaction, they classify the reaction.

So that is them meeting the curriculum expectations. But the pre-work is where they actually had to evaluate the safety of the molecules, of materials, safety of the process as well as the waste stream. That’s the green chemistry part. That's the sustainability piece, that's where the Lead Teacher Program leads them through. So where in my class students have to evaluate which reaction they do, another class in another school the teacher might prescribe them the four reactions, but those four reactions may not have even been the four safe ones, and even if they were the safe ones, that's the teacher doing green chemistry, not the students doing the green chemistry.

If the teacher does the green chemistry. That's good. You save the materials you save the cost, you are doing it safe for the students, but the students aren't getting the opportunity to evaluate the different procedures, and so that's where that topic goes from being just a very cursory cookbook lesson: mix these chemicals, write the reactions... which still they should hit the expectation.

But by doing it the green chemistry way, by doing it through the lesson plan developed through the Lead Teacher Program, then you actually have students being thoughtful about choosing them. They learn how to read an MSDS sheet because they need to do that in order to evaluate whether they're going to use iron

> or they're going to use nickel. And they have to figure out which one is the safer options they're going to use and which one produces a more safe byproduct.

This teacher integrated an understanding of green chemistry that includes teachers making design decisions for their students while also enabling their students to consider chemical safety throughout a lab. This approach to safety represents the first component of PCK from Magnusson et al. (1999): "orientations toward science teaching." For this teacher, science education involves students actively in the process of planning and carrying out investigations safely.

As exemplified in this case study, a green chemistry approach enables teachers to make decisions that minimize risks and include students actively in the safety process with appropriate levels of support. Students' understandings and abilities differ across grade levels, but even younger students can be guided to think through potential chemical or physical risks involved in an experiment. Therefore, green chemistry is not only a behind-the-scenes method for teachers. It can also support a direct approach to involve students in planning and carrying out investigations.

Case 2: An Empowering Experience of the Practice of Chemistry.

The second case study comes from an elementary classroom where the teacher guided students to make a type of glue from familiar ingredients. For a younger age group, it could be particularly challenging to imagine how to engage them with a complex area like green chemistry. However, this activity allowed students to experience a fundamental aspect of green chemistry: the creation of useful materials in ways that are safe for humans and the environment. Exploring this process at the elementary level can help other teachers consider how they are engaging students in the process of science.

The teacher first reminded students that they had previously talked about green chemistry. As a reminder, he summarized three “criteria” of green chemistry: materials that are safer to make and clean, just as effective, and, on an industrial level, cheaper. He then told the students that they would be making a green glue, which refers “not to the color” but to it being “made of household chemicals.” As further emphasis, he added that “you could eat it. It would taste nasty, but it wouldn’t hurt you.” Finally, he noted that other glues can contain many harmful chemicals, in contrast to the green glue which the students will make.

Throughout the procedure, the teacher guided students to work in pairs by talking through each step. First, he asked them to pick up materials from lab benches including baking soda, vinegar, and powdered milk which were already measured out into plastic cups. Then he had students label the cups on their own, noting that they can easily “find the vinegar with your nose, even with a mask on.” He reminded them of several safety rules when they are in the lab like being aware of the space around them and cleaning up any spills immediately. Next, he had them begin adding ingredients together. The teacher brought hot water to each table to mix in with the powdered milk and dissolve it. Then students needed to add the vinegar to the milk and mix until a curd formed, which they removed and put on a paper towel. The teacher collected the remaining liquid whey. Then students broke up the curd with a fork in the plastic cup and added some hot water as needed. Finally, they added some pinches of baking soda to neutralize the remaining solution and finish their green glue.

After finishing the procedure and cleaning up briefly, the teacher returned to the green chemistry criteria to decide if this glue fit. He emphasized that the materials were safer going in, since the students did not wear aprons or goggles, and going out, since they are able to pour everything down the drain at the end. He connected the importance of waste that goes down the drain because it can impact well water and aquifers in the local area. Then he suggested that they could calculate how cost-effective the glue was by adding up the ingredients. Finally, he asked: “does it work?” He continued by saying, “If it’s not effective, then there’s no point in doing it.” So, he suggested that students use their green glue to create a collage out of torn up construction paper in the last ten minutes of class. Then they could check the next day to see how their glue worked. Several students were proud to show me their collages as they finished.

Overall, this lesson exemplifies the second component of PCK from Magnusson et al. (1999): “knowledge and beliefs about science curriculum.” For elementary students, making glue from ingredients that they knew was an experience of green chemistry as a creative activity. The curriculum for this lesson and this teacher’s specific approach guided students through the process safely and effectively. Students of any age being able to hold something in their hands that they helped make is an empowering tool for learning. These students might not be able to restate the three criteria of green chemistry, but they could certainly show off the collages they created and know they had a hands-on role in creating something useful.

Case 3: Annotating the Twelve Principles with Connections.

Several teachers included the twelve principles of green chemistry directly in their classrooms, although each teacher necessarily adapted to different grade levels and contexts. The adaptations reveal significant expertise from these teachers about how to make the principles relatable to students. Specifically, real-life examples, industrial connections, or metaphors were all used to facilitate student connection with each principle.

In one of the classroom observations for a high school chemistry class, the teacher introduced the twelve principles as part of a unit on plastics. This case study provides an annotated outline of the principles as presented in this class, including the examples the teacher used for each, to provide a basis for other teachers to consider how or if they can integrate the principles directly.

In the first part of this observation, the class watched videos about recycling and ocean plastic clean-up as initial context to motivate the lesson. The teacher then asked students to consider examples, benefits, and drawbacks of plastics from their experience. To introduce green chemistry, the teacher explained that creating a biodegradable plastic would be one solution to the recycling issues. She gave a brief history of the development of green chemistry and stated this initial definition: “green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances.” Then students were asked to match up formal descriptions of each of the twelve principles with the titles, as shown below. They had time in pairs to work on that matching exercise on their computers. After about ten minutes, the teacher went through each principle and gave examples or annotations to make the ideas more relatable to the students. Connections to previous material, simplified descriptions, and real-life examples were used for different principles to explain them more fully. The examples serve as initial entry points and providing them here can allow teachers to consider their own examples or descriptions more easily.

Table 4. Annotated Principles of Green Chemistry from Case Study 3

Green Chemistry Principle	**Formal Description and Teacher Connections**
1. Waste Prevention	Formal Description: Prioritize the prevention of waste, rather than cleaning up and treating waste after it has been created. Plan ahead to minimize waste at every step.
	Simplified Description: “Whenever you’re doing a chemical reaction, it ends up producing some waste… maybe not everything you have in that reaction actually gets used, so the whole point is to limit that waste.”

2. Atom Economy	Formal Description: Reduce waste at the molecular level by maximizing the number of atoms from all reagents that are incorporated into the final product. Use atom economy to evaluate efficiency.
	Simplified Description: “Whatever atoms you start with and put into the reaction should be what you’re taking out of the reaction.”
	Connection to Previous Material: “If we remember working with our molymods [molecular modeling kits], we were making all of those different chemicals. We added a bunch of chemicals together, and those atoms are what ended up in our product… Basically: do you have atoms that are hanging out, or are they all present in your products?”
3. Less Hazardous Chemical Synthesis	Formal Description: Design chemical reactions and synthetic routes to be as safe as possible. Consider the hazards of all substances during the reaction including waste.
	Simplified Description: “Basically that means that we’re designing safe reactions.”
	Real-life Examples: “If I’m talking about a safe reaction, what are we not going to be doing during a safe reaction? What would that not look like?... We wouldn’t be lighting things on fire. We wouldn’t be causing things to explode… This actually happened to me when I was in undergraduate. I was working in a research lab, and someone was working with a reaction that was very sensitive to water. And they actually ended up having a bunch of glassware explode on them that day…They were doing everything correct; it was just humid that day.”
4. Designing Safer Chemicals	Formal Description: Minimize toxicity directly by molecular design. Predict and evaluate aspects such as physical properties, toxicity, and environmental fate throughout the design process.
	Simplified Description: “This is going more into the toxicity of it. So how toxic is that chemical compared to others?”
	Real-life Examples: “A big area you can kind of think about designing safer chemicals are actually with your skincare and healthcare products. So are there any skin or healthcare things that you try to avoid?... Botox might be one of them. That’s quite literally putting something poisonous in it so that it freezes that area… Lead, yeah, so pencils are now made of graphite, so we’re not ingesting a lot of lead… Asbestos, that is pretty common with a lot of household materials.”

5. Safe Solvents and Auxiliaries	Formal Description: Choose the safest solvent available for any step. Minimize the total amount of solvents and auxiliary substances used, as these make up a large percentage of the total waste created.
	Real-life Examples: “This one is a little bit tricky to understand… One of the safest solvents you can actually use is water. Water is a nice, safe solvent that we use in most chemical reactions to mix a lot of those powders and things.”
6. Designed for Energy and Efficiency	Formal Description: Choose the least energy-invasive chemical route. Avoid heating and cooling, as well as pressurized and vacuum conditions (i.e., ambient temperature and pressure are optimal).
	Real-life Examples: “What would it look like to not be energy-efficient? If we’re not energy-efficient, what are we using?... Fossil fuels, yeah, so that’s going into more the renewability of it. But in terms of energy, maybe we’re using fossil fuels to power up a gas generator that we’re pulling energy from. Anytime you have to heat up a reaction, you’re using electricity. That is not energy efficient. Anytime you have to cool it down. Anytime you have to add pressure to it. All of those situations require energy that you don’t need. If you could do a reaction just on your tabletop without doing anything, that is a nice, energy-efficient reaction.”
7. Use of Renewable Feedstock	Formal Description: Use of chemicals which are made from renewable (i.e., plant based) sources, rather than other, equivalent chemicals originating from petrochemical sources.
	Real-Life Examples: “That’s basically anything that’s not oil-based, so like corn, potato, tapioca. All of those feedstocks we can grow again and again, so those are all considered renewable resources.”
8. Reduce Derivatives	Formal Description: Minimize the use of temporary derivatives such as protecting groups. Avoid derivatives to reduce reactive steps, resources required, and waste created.
	Simplified Description: “We’re trying to minimize how many side products that get made.”
	Connection to Previous Material: “A lot of the time, the way that I’ve taught you a reaction,” teacher says while drawing an example reaction on the board, “is you start with your reactants, and all of that goes together to make your product. In real life, that’s not what happens. You get some side products. You get a whole lot of different things happening. Maybe you get like part of A mixed with part of B. So you might be able to get a lot of derivatives from that reaction, and this is all about how efficient your reaction is. The whole goal is that you don’t get a lot of these derivatives.”

9. Catalysis	Formal Description: Use catalytic instead of stoichiometric reagents in reactions. Choose catalysts to help increase selectivity, minimize waste, and reduce reaction times and energy demands.
	Simplified Description: “We’re using a catalyst to help speed up that reaction, and it also reduces waste and reduces the reaction time. Basically, we’re speeding it up.”
	Real-life Example: “What is a catalyst that got you to school today?... Your car, okay, so your car got you to school. Is your car getting the education it needs right now? No, so your car helped get you here. It got you here quicker so that you can learn and then you can go home. That is like a catalyst. It’s not part of the reaction. It’s not part of your learning, but it’s helping you make that learning possible.”
10. Design for Degradation	Formal Description: Design chemicals that degrade and can be discarded easily. Ensure that both chemicals and their degradation products are not toxic, bio accumulative, or environmentally persistent.
	Simplified Description: “That basically means: can it degrade and dissolve in whatever material? Is it going to break down and not just make a little microplastic? Ideally when it degrades, it degrades into things that are not toxic, because a lot of times things degrade into things that are toxic. So how can we prevent that toxicity?”
11. Real-time Prevention	Formal Description: Monitor chemical reactions in real-time as they occur to prevent the formation and release of potentially hazardous and polluting substances.
	Simplified Description: “That’s all about preventing hazardous pollutants. That one’s pretty self-explanatory.”
12. Safer Chemistry for Accident Prevention	Formal Description: Choose and develop chemical procedures that are safer and inherently minimize the risk of accidents. Know the possible risks and assess them beforehand.
	Simplified Description: “You don’t want to have accidents, especially if we want to bring this to a mass scale. So that’s really taking in all of the risk factors and seeing ‘are those risk factors going to affect us?’”

These initial examples were intended as an overview of the principles before continuing the unit on plastics where the students would apply the principles more directly. After these examples, the teacher also acknowledged that “if you didn’t get all of these, that’s okay. A lot of these definitions are very technical. We’re going to continue working with these throughout the year as we’re learning these different principles.” Finally, the teacher assigned one principle each to pairs of students for them to explore more deeply by watching a video and answering a series of prompts. In subsequent days of this unit, students created their own plastics based on polylactic acid with a variety of starting materials and additives.

Overall, this case study helps to address one of the central issues of green chemistry education at the K-12 level, which is how to adapt a system that was developed for an industrial and research context into educationally appropriate and valuable content. Teachers often adapt green chemistry by providing examples that make sense developmentally and culturally to their students. The expertise needed to make these kinds of connections was one of the main ways that PCK was initially described by Shulman (1986, p. 9). This classroom provides just one glimpse into that process from a high school teacher’s perspective.

The supplemental examples that teachers used for green chemistry represent another subset of expertise that varies depending on local context and how familiar the teacher is with the material. Knowing appropriate examples would fit into the third component of PCK from Magnusson et al. (1999): “knowledge and beliefs about students’ understanding of specific science topics.” Naturally these examples would differ based on classrooms, local regions, cultural background of students, and age range.

Similarly, the interview code list also included “Regional Connections” to identify times when participants shared a way that they used a local context to connect students with chemistry concepts and the world. For example, a teacher shared:

> I teach in… a small town, all cranberry bogs. And most of my students either own bogs or their relatives do… So, when you talk about sustainability, hazardous waste going into their water system, things like that. That's their livelihood… it takes a

> million gallons of water per bog acre per year to run a bog. And these people own 20, 30 acres of bogs. So, they know the concept of: if you're polluting over here, it's going to damage that bog over there... and we have a bog right behind our building. We are one of the largest aquifers in the state... So, it's all lakes, bogs, and ponds all around our schools. So, we really try to home in on sustainability, green science, environmental science, things like that with the kids.

Contextual examples like this one can help to illustrate content and motivate students to engage with material. These connections are similar to the approach of place-based education (Sobel, 2013), and they help to capture the PCK that teachers develop for their individual classrooms.

Case 4: An Experimentation Mindset.

Finally, many teachers explained the shift toward experimental inquiry that is intimately connected with green chemistry. In one set of classroom observations, a teacher had developed a self-paced unit about soap and hand-washing for a middle school class. The driving question for this unit was “how do soaps work?” Throughout the unit, students had the opportunity to make and test a hand soap, comparing its performance with their initial experience of washing off glow-powder from their hands using commercial soaps.

The teacher’s role in this classroom was largely to propose questions for the students and ask them to explain their reasoning or to give evidence for their conclusions, a method heavily reflective of the NGSS Lead States (2013). The types of questions varied based on the abilities of the students and where they were in the experiment. At one point, the teacher warned a student to think through their experiment thoroughly, saying, “I’m going to ask you a bunch of questions before you finish, so make sure you understand.” In fact, questions were the vast majority of ways that the teacher spoke with students and provide insight into how this teacher views the experimental process.

Some of the questions that the teacher asked included:

1) “What are you going to do? How are you going to do that?”

2) “Is this making sense?”
3) “What is a rule of good chemistry? What is important to remember when you are doing chemistry?”
4) “What do you mean by ‘precautions?’ What would be an example of a safety precaution?”
5) “How will you be safe? What kinds of things will you do to stay safe?”
6) “What are you going to do next? You get to decide.”
7) “What are you doing for your second iteration?”
8) “What did we learn?”
9) “How is [the soap] going to take away the germs? And how is homemade soap different from other types, like Dove?”
10) “What scents are you using [for your soap]? What additives are you using? What are you putting in yours?”
11) “What did you notice about the pictures you took before and after washing your hands?”
12) “Other groups had pictures that looked like this, but yours looked like that. Why do you think that is?”

The teacher rarely gave direct answers or instructions to students and instead focused on prompting their own reflection on the experiment and their conclusions. At times, the teacher gave advice to students about the experimental procedure to limit the range of options, such as adding essential oils one drop at a time. The procedural scaffolding supported students to focus on the scientific process of investigation and explaining their reasoning.

Because of the inherent safety of green chemistry, this teacher was better able to construct the classroom in a way that supported this type of open and self-paced inquiry. This approach exemplifies the fourth component of PCK from Magnusson et al. (1999): “knowledge and beliefs about assessment in science." Verbal assessments gave this teacher direct information about students' understanding in addition to the written assignments included in the unit. For a green chemistry approach that can tend to be more variable and student-directed, this type of assessment works well. The example shared in chapter 1 (pp. 2-3) also exemplified an approach to experimentation that supports student reflection and justification for their experimental procedure. Labs and activities are built around scientific explanations more than accurate results or correct answers. Green chemistry does not require this assessment approach, but it does allow for significant flexibility and explicit scaffolding from the twelve principles to enable students to test and defend their ideas safely and thoughtfully.

Green Chemistry Content Representation

Based on the interview summaries and classroom observations, I propose an initial framework for a Content Representation (CoRe) for green chemistry education in K-12 classrooms. As Loughran, Berry, and Mullhall (2012) caution before presenting each CoRe,

> The CoRe outlines some of the aspects of PCK "most attached to that content," but it is not the only representation. It is a necessary, but incomplete, generalization that helps to make the complexity accessible and manageable; it is neither complete nor absolute. (p. 25)

The descriptions in Table 5 explain the main components of this CoRe connected with the relevant components of PCK from Magnusson et al. (1999): (1) orientations toward science teaching, (2) knowledge and beliefs about science curriculum, (3) knowledge and beliefs about students' understanding of specific science topics, (4) knowledge and beliefs about assessment in science, and (5) knowledge and beliefs about instructional strategies for teaching science (p. 97).

Table 5. Initial CoRe Framework for K-12 Green Chemistry Education

CoRe Area	Description	Relevant PCK Components(s) from Magnusson et al. (1999)
Chemical Safety	Green chemistry is inherently safer, smaller scale, and cost effective compared to traditional curricula. It encourages teacher and student ownership of chemical safety throughout the classroom.	1
Practice of Chemistry	Green chemistry provides an empowering experience making and using chemicals, helping students to imagine creative possibilities of the future.	1, 2
Teacher-facilitated Connections	Teachers support their students' engagement with green chemistry by making connections with industrial, community-based, or real-life examples.	3, 5
Experimentation Mindset	Green chemistry supports classrooms to be exploratory, design-oriented, and based in problems and solutions. Students are supported to make claims and cite evidence to support their conclusions.	4, 5

The four CoRe areas reflect the four case studies above but are generalized to be applicable to more classrooms. Overall, the CoRe summarizes the expertise of teachers in LTP beyond traditional chemistry content and classroom management strategies. These four areas speak to the unique contribution that green chemistry makes to K-12 science education and can serve as a basis for further reflection and development by teachers and researchers. Some of the areas overlap, but each one highlights an emphasis that green chemistry brings compared to more traditional chemistry curricula.

First, green chemistry makes chemical safety more explicit for teachers and students. By using less hazardous chemicals and smaller scales, experiments are inherently safer for students and for the environment. Everyone in the classroom can take ownership for safety through open conversations and applying the twelve principles to their experiments. Teachers who choose to incorporate green chemistry view learning as a shared process with students in their classroom. An added benefit of chemical safety also includes cost savings from materials, waste disposal, and addressing risks of injuries.

Second, green chemistry supports an empowering experience of chemistry as a creative science of solutions. K-12 green chemistry curricula should be designed to encourage engagement with this practice of chemistry rather than simply a science of following procedures. Through green chemistry, teachers and students can develop a perspective of science that is capable of confronting future issues in ways that protect people and the planet.

Third, green chemistry requires teachers to develop a wide range of connections to real-life and their local region in order to connect students with the content. A contextual approach to chemistry engages students and motivates their learning far beyond the classroom. Simplified descriptions and connections to previous material also serve to weave green chemistry into existing curricula.

Finally, green chemistry includes an experimentation mindset where students are assessed based on their ability to cite evidence from experience to justify their claims. These classrooms are exploratory, design-oriented, and based in finding solutions to real world problems. Both instruction and assessment must be adapted to this type of environment.

CHAPTER 7

CONCLUSION

"I know I'm teaching something that's valuable beyond the lesson. It's something that's valuable to humankind at the end of the day."–Lead Teacher

Studying the Lead Teacher Program allowed for exploration of the deep expertise of K-12 educators who are developing green chemistry practices. After exploring the landscape of green chemistry and environmental curricula, this project sought to develop a grounded theory from the perspective of participants in LTP. The methodology triangulated data between 28 semi-structured interviews, field notes of program activities, and sets of classroom observations of five teachers. A full program evaluation explored the activities, successes, and potential improvements developed from interview transcripts. Four case studies were developed as Professional and Pedagogical Experience Repertoires (PaP-eRs) based in classroom observations and extended examples from interviews. Finally, a Content Representation (CoRe) for K-12 green chemistry education was constructed with four areas including chemical safety, the practice of chemistry, teacher-facilitated connections, and an experimentation mindset.

Transferable Program Strengths and Improvements

Future teacher development programs can benefit from this project to form supportive communities of teachers attempting to implement an innovative curriculum. Both the practical evaluation of LTP and the development of green chemistry PCK in this project can support future programming. As Magnusson et al. (1999) explained, "the practical value of pedagogical content knowledge as a construct has to do with its potential to define important dimensions of expertise in science teaching that can guide the focus and design of pre-service and in-service teacher education programs" (p. 116). Programs should consider fostering regional networks of current teachers who share similar contexts and goals. Peer teachers are better able to connect and share relevant experiences with each other. LTP also highlighted the importance of supporting a sense of professionalism for K-12 teachers that acknowledges their expertise and gives them venues to share it. Other programs will need to balance between allowing for teacher autonomy and assigning specific tasks to participants. Different models for program alumni can also be developed to retain their individual expertise while focusing program energy on newer participants.

Future Research Directions

The ultimate success of this research will be in prompting conversations among K-12 teachers, teacher trainers, and academic researchers to build on the foundation of green chemistry education. A major goal is to publish and share results in both professional and popular venues to encourage these reflections and conversations. The examples of PCK in the CoRe and PaP-eRs are designed to facilitate these conversations as a starting point and common place for comparison. Three potential areas for publication include the full program evaluation, an understanding of K-12 green chemistry education through the CoRe and PaP-eRs, and a commentary on the barriers to implementation for K-12 teachers with suggestions from environmental education research for overcoming these barriers. Each of these areas is in process and will contribute significantly to current scholarship in chemistry education.

A critical component of any educational program is ultimately its effects on students in the short and long term. With a more well-defined foundation for green chemistry in K-12 classrooms, further work will be needed to study how this approach affects student learning

(Bransford et al., 1999). With a basis for defining PCK for green chemistry, connections could be investigated more thoroughly between teachers' levels of expertise and student outcomes (Coe et al., 2014). These types of connections would be critical to advancing green chemistry education and continuing to grow LTP.

Finally, I return to the framing metaphor for this dissertation. The future cultivation of teacher expertise in the current landscape of green chemistry can benefit from the results and discussion covered here. Developing pedagogical content knowledge among K-12 teachers has served to advance to prominence and understanding of green chemistry. And if continued to be developed in ways that are sustainable for participants and staff, the Lead Teacher Program and other work by Beyond Benign can continue to bear fruit for many years to come.

The Reaction Equation of Exceptional Chemistry Teaching

To return to the opening question from chapter 1, what makes an exceptional chemistry teacher? We might conceptualize a reaction equation for that process where the right amount of content knowledge in chemistry is mixed with enough pedagogical knowledge to produce the desired teaching and, therefore, student learning. However, the reality of this process is much more complicated. There is a highly variable yield of student outcomes. The perfect conditions of a classroom are difficult to maintain. And any teacher knows that there are some unproductive combinations of content and pedagogy that take away from the desired reaction. In short, this approach to exceptional teaching is unsustainable.

What is needed is a green approach to K-12 education that more directly supports exceptional teaching and learning. The Pedagogical Content Knowledge developed with teachers in LTP through this project can act as a catalyst to provide kinetic patterns and help teachers to identify the most productive pathways for their own classroom. The approach of green chemistry more broadly can act as a renewable energy source to drive the reaction thermodynamically. Together, the knowledge and practices explored in this project can make exceptional chemistry teaching more sustainable and attainable for K-12 teachers. As one Lead Teacher shared, that vision will truly be "something that's valuable to humankind at the end of the day."

APPENDIX A

SAMPLE CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH

Project Title: Pedagogical Content Knowledge in the Lead Teacher Program
Researcher: Philip Nahlik
Faculty Sponsor: Patrick Daubenmire

Introduction:
You are invited to volunteer to take part in a research study being conducted by Philip Nahlik under the supervision of Dr. Patrick Daubenmire in the Department of Chemistry and Biochemistry at Loyola University of Chicago. You are being asked to participate because of your connection with the Lead Teacher Program.

Please read this form carefully. You will have the opportunity to ask any questions or request clarification before deciding whether or not you choose to participate in the study.

Purpose:
The purpose of this study is to describe the impact of the Lead Teacher Program. By working with participants to construct a common understanding of program outcomes, we hope to support the development of this innovative community and share best practices with the wider education community.

Procedures:
In order to collect data to address the research questions and hypotheses, we are asking you to participate in a phone call of 30-60 minutes in length. Topics covered might include your experience in the Lead Teacher Program, your views about science education, anecdotes about your classroom activities, and reflections on your own development as an educator. These calls will be audio recorded for accuracy. You will also be asked to complete a short demographic survey and a worksheet about your teaching practices. Our research team will be observing regular program activities like the summer summit, monthly phone calls, and any other large group gatherings. Notes about these activities will help to supplement other research data.

Risks/Benefits:
This research poses no foreseeable risks above normal, daily professional activity as a teacher. No sensitive information will be covered, and no data will be used in an evaluative manner in connection with your position at your school or in the Lead Teacher Program. Interview sessions will follow accepted practices in the field. In research publications, the researchers will attempt to provide accurate descriptions with the use of direct quotes and by providing context where necessary. We expect that the opportunities for reflection and conversation will enhance your development within the Lead Teacher Program. Furthermore, the information you provide could improve the program directly or benefit future teacher education programs.

Confidentiality:
All audio data will be kept on a password-protected computer at Loyola University Chicago. After transcriptions and coding are completed, the files will be destroyed. You may choose below how you wish to be identified in publications based on these data.

Voluntary Participation:
Participation in this study is voluntary. If you do not want to be in this study, you do not have to participate. Even if you decide to participate, you are free to withdraw from participation at any time without penalty by contacting any member of the research team. Your choice not to participate means that data collected from you will not be included in the research analysis. There are three possible levels of participation which you may choose in this study:

________ Full Participation: Your full name will be included with any direct quotes or data that you provide in any publications which use this research.

________ Confidential Participation: Direct quotes and data that you provide will be included with a pseudonym and restricted identifiable details to avoid erroneous identification in any publications which use this research.

________ Minimal Participation: Direct quotes and data that you provide will not be included in any publications.

Compensation:
No compensation will be provided for this study.

Contacts and Questions:
If you have questions about this research study, please feel free to contact:
Philip Nahlik at pnahlik@luc.edu, or
Patrick Daubenmire at pdauben@luc.edu.

If you have questions about your rights as a research participant, you may contact the Loyola University Chicago Office of Research Services at 773.508.2689.

Statement of Consent:
Your signature below indicates that you have read the information provided above, have had an opportunity to ask questions, and agree to participate in this research study. Additionally, please initial above next to the level of participation you would prefer.

____ ________________
Participant's Signature **Date**

____ ________________
Researcher's Signature **Date**

APPENDIX B

INTERVIEW PROTOCOL

Interview Questions for Teacher Participants

1. Do you consent to having this interview recorded for accuracy?
2. Could you tell me about your background, where and what you teach?
3. Which programs with Beyond Benign have you participated in (online course, Lead Teacher Program, webinars, curriculum, etc.)? Tell me about how you got involved.
4. What other professional development activities have you participated in, outside of Beyond Benign?
5. If you participated in LTP, how has your teaching approach changed as a result?
    a. What do you think are the main outcomes of LTP? What would be your elevator pitch for the program?
    b. How have you changed personally?
    c. Is there anything you would change about LTP?
6. You completed a Content Representation worksheet before this interview. Tell me about your experience with that worksheet.
    a. Did you learn anything in reflecting on your teaching practice in this way?
    b. Can you describe an example of a lesson or classroom activity that influenced your thinking on this worksheet?
    c. Is there anything the worksheet left out that you would want to add?
7. How would you describe Green Chemistry and why it is important?
8. Knowing what you know about my evaluation work so far, do you have any suggestions or recommendations for me? How would you approach this study? Talk about timeline.
9. Is there anything else you want me to know about you as a teacher?

Questions for Staff

1. Do you consent to having this interview recorded for accuracy?
2. Tell me a little about yourself, your background, and your work.
3. Tell me about how you got involved with Beyond Benign. Which programs have you participated in (online course, Lead Teacher Program, webinars, curriculum, etc.)?
4. Are there other significant education programs you have participated in, outside of Beyond Benign?
5. Focusing on your experience with LTP:
    a. What do you think are the main outcomes of LTP?
    b. What is your elevator pitch for LTP?
    c. Do you have any stories about how particular teachers have changed/grown?
    d. Is there anything you would change, update, or nuance about LTP?
    e. What might the “Certified” role look like?
6. You saw the Content Representation worksheet and heard about PCK before this interview. Tell me about how these concepts compare with LTP.
    a. Did any parts strike you as connected or disconnected from program activities?
    b. Can you describe an example of a part of LTP that seems connected to this understanding of teacher expertise?

c. Is there anything that the worksheet or the concept of PCK left out that you would want to add?

7. How would you describe Green Chemistry and why it is important?
8. Knowing what you know about my evaluation work so far, do you have any suggestions or recommendations for me? How would you approach this study? Are there any questions I should be asking that I have not yet? Talk about timeline.
9. Is there anything else you want me to know about you as a staff person?

APPENDIX C

LETTER OF COOPERATION TEMPLATE

[PLEASE COPY ONTO SCHOOL LETTERHEAD]

Philip Nahlik
Loyola University Chicago
1032 West Sheridan Road
Chicago, Illinois 60660

[DATE]

Dear Mr. Nahlik,

On behalf of [TEACHER NAME] at [SCHOOL NAME], it is my pleasure to welcome you to observe several class sessions as part of your research with the Lead Teacher Program through Beyond Benign. The project's goals of better understanding teacher training programs for Green Chemistry fit well with our school's approach to education.

I understand that you will work with our teacher to schedule and conduct a classroom observation on [DATE], following school policies and research guidelines to maintain the safety and confidentiality of everyone involved. Furthermore, I understand that no identifiable student data will be recorded but that parents or guardians will still be notified in advance if they wish for their child to be excused from that class session. I will support our teacher and inform you of any additional school policies related to these observations.

We look forward to this ongoing opportunity to collaborate and support the growth of training programs for K-12 science teachers.

Sincerely,

[ADMINISTRATOR SIGNATURE, NAME, AND ADDRESS]

APPENDIX D

MESSAGE FOR PARENTS

Hello, parent(s) or guardian(s),

You are receiving this message because your child's teacher <<NAME>> is participating in a research study conducted by Philip Nahlik under the supervision of Dr. Patrick Daubenmire at Loyola University Chicago. This study involves the teacher's participation in a professional development program for science teachers.

As part of the study, digital and/or in-person classroom observations will be conducted and video recorded for three class sessions throughout the school year. These recordings will be kept on a password protected device at Loyola University Chicago and destroyed when the project is completed (about two years total). Your child's image and/or voice might be captured on these videos. However, since the study is focused on the teacher's behavior, no students will be identified in any way in the recordings or research publications. Our research team will follow accepted practices to limit your child's exposure, including only limited information about the teachers and schools as well as never recording any child's personal information in any form.

Even though this research poses minimal risks, you have the right to request that your child does not participate in classes which will be recorded. If you make this request, an alternate assignment or activity may be provided by the teacher, without penalty to the student. If you do not want your child to participate, please contact their teacher directly to make this request. Unless you make this request, the classroom observations will be recorded as planned.

If you have questions about you or your child's rights in relation to this research, you may contact the Loyola University Office of Research Services at 773.508.2689.

Sincerely,
Philip Nahlik
Loyola University Chicago

APPENDIX E

BLANK CORE WORKSHEETS

Content Representation (CoRe) of Green Chemistry in the Lead Program

Adapted from: Loughran, J., Berry, A., & Mulhall, P. (2012). Understanding and developing science teachers' pedagogical content knowledge. Sense Publishers.

Instructions:

1. From the GoogleDoc menu, select either “Download” or “Make a Copy” to edit your own version of this document.
2. Then complete the following questions and CoRe table based on your understanding of Green Chemistry and experience so far as a Lead Teacher. This structure is designed to help you share your deep, expert knowledge about teaching.
3. Focus on 5-8 “Big Ideas” that cover your approach to Green Chemistry or a certain unit of content. These might be student learning objectives that you have already identified.
4. Try to be descriptive with sentences or detailed bullet points for as many boxes as possible without including external links. Part of the exercise is creating concise descriptions of your teaching practices.
5. We will have conversations to develop these tables throughout this year, so your first draft might differ significantly from the final version. Do your best in this first round!

Name: ______________________________

School Name and City: ______________________________

Grade Level: ______________________________

Subjects Taught: ______________________________

Years of being a Lead Teacher: ______________________________

Focus Unit of this CoRe: ______________________________

	Big Idea A	Big Idea B
Title or description of the big idea.		
What you intend students to learn about this idea.		
Why it is important for students to know this idea.		
What else you know about this idea that you do not intend students to know yet.		
Difficulties, limitations, or misconceptions connected with teaching this idea.		
Knowledge about students' thinking which influences your teaching about this idea.		
Other factors that influence your teaching of this idea.		
Teaching procedures (and particular reasons for using them to engage with this idea).		
Specific ways of ascertaining students' understanding or confusion around this idea.		

	Big Idea C	Big Idea D
Title or description of the big idea.		
What you intend students to learn about this idea.		
Why it is important for students to know this idea.		
What else you know about this idea that you do not intend students to know yet.		
Difficulties, limitations, or misconceptions connected with teaching this idea.		
Knowledge about students' thinking which influences your teaching about this idea.		
Other factors that influence your teaching of this idea.		
Teaching procedures (and particular reasons for using them to engage with this idea).		
Specific ways of ascertaining students' understanding or confusion around this idea.		

	Big Idea E	Big Idea F
Title or description of the big idea.		
What you intend students to learn about this idea.		
Why it is important for students to know this idea.		
What else you know about this idea that you do not intend students to know yet.		
Difficulties, limitations, or misconceptions connected with teaching this idea.		
Knowledge about students' thinking which influences your teaching about this idea.		
Other factors that influence your teaching of this idea.		
Teaching procedures (and particular reasons for using them to engage with this idea).		
Specific ways of ascertaining students' understanding or confusion around this idea.		

	Big Idea G	Big Idea H
Title or description of the big idea.		
What you intend students to learn about this idea.		
Why it is important for students to know this idea.		
What else you know about this idea that you do not intend students to know yet.		
Difficulties, limitations, or misconceptions connected with teaching this idea.		
Knowledge about students' thinking which influences your teaching about this idea.		
Other factors that influence your teaching of this idea.		
Teaching procedures (and particular reasons for using them to engage with this idea).		
Specific ways of ascertaining students' understanding or confusion around this idea.		

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VITA

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