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Using Green Chemistry to Build Community: How Transformational Learning Impacts the Building of a Community of Practice

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Abstract

Green Chemistry education is a widening field, seeking to include educators at all levels collaboratively in the process of transforming outdated chemistry practices. Qualitative research methods were used to interview three key collaborator groups at Beyond Benign, a green chemistry education organization, who are considered part of the Green Chemistry Community of Practice (GCCoP). This was done to develop a strategic plan to 1) explore how the Beyond Benign team and K-12 teachers see themselves as part of one GCCoP; 2) to ascertain how to bring the K-12 program into alignment with the organization's evolving mission; and 3) to discover approaches for improving K-12 and Higher Ed collaboration and engagement, creating new possibilities for K-12, and bringing the two communities back into one evolving GCCoP. What was discovered through interviews with the Beyond Benign team, K-12 teachers, and higher ed faculty was that there were several challenges, but many possibilities for collaboration. Transformational learning that generates engagement, agency, and a desire for change was a theme that educators at all levels, from elementary through grad school, described as important to learning and building community around green chemistry to generate changes in the wider world, and draw more people into GCCoP.

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Beyond Benign: K-12 Strategic Plan

Green chemistry is a fairly recent framework for looking at chemistry and the physical sciences with a sustainable lens. Its main tenets involve practicing chemistry with an eye for safety, replacing harmful chemicals with chemicals that are benign that also function equal to or better than the harmful ones, and doing this with the same or better cost. There are twelve principles that define green chemistry as a discipline that is transforming chemistry into a more sustainable field, with the potential to have a similar impact on the physical sciences. As it is a fairly new branch of chemistry, with the first PhD graduate in the world occurring in 2005, there is much to be done to bring this important transformation into the practice of chemistry globally. Beyond Benign, an organization founded by that first Green Chemistry graduate, seeks to bring the transformative learning and practice of green chemistry into higher education (college/post-secondary), K-12 (kindergarten through twelfth grade/primary, secondary) education and industry spaces, and build a community of green chemistry educators, practitioners, and collaborators.

Communities of Practice (CoP) are defined around shared passion for "something they do while they learn how to do it" with regular interaction (Kezar et al., 2018, p.832), and can collaborate to become Communities of Transformation (CoT), "communities that create and foster innovative spaces that envision a new future" (p. 832). There are principles and ideas around education and community building that have evolved through practice and in developing and engaging communities of practice with both K-12 educators and higher ed educators. Each community of practice that Beyond Benign collaborates within is passionate about their green chemistry practices.

Beyond Benign is an organization focused on green chemistry education and fostering community around green chemistry educators, primarily, from kindergarten through doctorate degree (K-20), and institutions and industry interested in evolving their sustainability practices. Currently Beyond Benign as an organization perceives itself and its function as collaborating with and developing CoT, which in the past few years have mainly centered on higher ed. This Green Chemistry CoT they have fostered the development of and collaborated in is thriving and growing globally. Virtual programs and platforms combined with in person conferences and a growing support team, supported by funding and development are generating the results expected from this focus. Unfortunately, the K-12 program has not evolved alongside it.

The K-12 CoP created transformational learning, as Mezirow (1997) describes, with the teachers who participated, particularly in the Lead Teacher Program (LTP) that took place from 2016-2021, providing in-person professional development and a supportive hybrid learning community with the goal of creating green chemistry leaders in school districts through the process, like a train-the-trainer program. Participants contracted in this program for three years, and teachers were accompanied by Beyond Benign's Executive Director, the K-12 Director, and K-12 educators with green chemistry experience to do this. Initially, due to grant funding, much of this was done in person through trainings and annual summits that brought this CoP together for learning, support and collaboration. Many of the teachers went on to complete projects with their schools and create Open Educational Resources (OER) for use by teachers nationally and internationally. The program was funded by a one million dollar grant initially. The current cohort of Lead Teachers will complete their contract at the end of 2024, with no current plan to continue the program.

Due to shifts in leadership, the lack of a support team, a major shift away from in-person seminars and trainings, loss of major funding and restrictions of state funding, the K-12 program has suffered some setbacks. Many K-12 educators in the Beyond Benign CoP had benefited from the support of higher ed partners, particularly with regard to professional development (PD) training and support. Online courses were developed in conjunction with the faculty who were part of the collaboration and PD. Teachers who had gone through the Green Chemistry PD taught the Online Courses which were set up, with credentialing opportunities for teachers to register for and take in the summer.

Higher ed CoT has grown by building virtual connections across national and international borders and finding points of commonality to collaborate with little regard to those borders, with funding that supports the work without the state and regional restraints that are placed on K-12 school systems. As these higher ed endeavors were successful, more team members were hired to support the growing work. More higher ed institutions signed the Green Chemistry Commitment (GCC), the flagship program for higher ed, where institutions commit to green chemistry practices in their labs and chemistry departments and benefit from access to grants and other opportunities as a signer, committing to bring their practices and teaching in line with Green Chemistry principles as they participate in the CoT. More activities were generated through collaboration and demand. K-12 communities do not have that fluidity in their ability to collaborate as they are often bound by state funding, state standards and regional bureaucracies.

By examining what has worked in the past to create transformational learning and seeking to connect the two CoP, particularly where there is overlap and benefit to both of them, Beyond Benign hopes to create a strategic plan that will foster growth in the K-12 CoP, continuing to support the development of K-12 educators. Partnerships between K-12 educators

and institutions and the higher ed institutions in their regions may be able to alleviate some of these challenges. Beyond Benign seeks to create Communities of Transformation involving both higher ed and K-12 CoP. CoT are a form of CoP that are dynamic and have to adapt with changes that occur in their operation and perspective.

Literature Review

Exploring research about K-12 and higher education collaborations has led to a deeper understanding of how these two distinct CoP can find commonality and learn from one another. Much of the research is focused on higher ed supporting K-12 educators in PD or on supporting schools through programs developed by higher ed. For the two distinct CoP to become regular collaborators it would be useful for them to understand the benefits that would occur for both CoP from the collaboration. For K-12 the benefits of expertise, particularly in Science, Technology, Engineering and Math (STEM) fields, on teacher development and curriculum are the most noted by researchers, with good reason, as STEM reform in schools is much needed. As Blomgren (2018) explored OER, which are resources that are developed by educators for educators and are free to access, adapt and collaborate with, the process of developing these resources was found to help educators be more collaborative, adoptive and inclusive, also assisting both higher ed and K-12 educators to be more aware of "changes occurring in the communities where they teach" and be better community partners as they work together to address these issues (Blomgren, 2018, p.62). Other researchers note collaborative benefits for higher ed faculty, such as increased understanding of pedagogy due to the expertise of the K-12 teachers, and a deeper understanding of the settings where they are conducting research (Foster et al., 2010; Tomanek, 2017). Additionally, increased collaboration led to shifting perceptions of expertise coming from higher ed faculty only and opened perceptions of faculty to the expertise

of teachers, and the perceptions of teachers in seeing themselves as experts (Burrows, 2015). Faculty and teachers both benefit from increased understanding of cultural relativity, and their collaborations help them apply it more meaningfully in both settings (Interviews with Beyond Benign Lead Teachers, 2023). Bridges between high school and college STEM programs can be built as knowledge is gained regarding both settings, which, according to Subramian and Clark (2016), can help reduce the "STEM attrition resulting from lack of knowledge about these fields" (Abstract section). Pre-service teachers are better supported because faculty and teacher mentors are collaborating and often create a bridge of understanding between the two CoP (Tomaneck, 2017). Another concept that is enhanced through building this bridge between high school and college, particularly in STEM programs is *vertical alignment.* This concept is discussed by Burrows et al. (2014) as "meaningful learning by using tasks that actively engages the learner in searching for relationships between his/her existing knowledge and the new knowledge" (p.1380) and includes the concept of not only building on knowledge from one level to the other, but also seeking to connect that knowledge in the real world outside of the classroom.

Communities of Practice

The concept of Communities of Practice (CoP) was coined in 1991 by Jean Lave, a cultural anthropologist, in collaboration with her then student, Etienne Wenger in *Situated Learning: Legitimate Peripheral Participation*, a study of apprenticeships as a learning model, that examined the unique collaboration and mutual learning between apprentices and their masters, as Wenger-Trayner and Wenger-Trayner (2015) describe on their website, "community that acts as a living curriculum for the apprentice" (Wenger-Trayner, 2015, paragraph 15). Wenger (1998) described CoP as communities we participate in, whether we think about them or not, in our work, hobbies, home life and school, that "informally bind [us] by what [we] do

together" (p.3). The three dimensions that define a community of practice, according to Wenger (1998), are the *joint enterprise* of what the community agrees it is about; the *mutual engagement* that determines its functioning and connects the group socially; and the *shared repertoire* of things it has produced or agreed on as far as resources, language, terms, which unfold while they are together. A CoP, as described by Wenger (1998), is different than a team or network because it is the "shared learning and interest of its members" and what it is "about," not just the relationships (p.5) that drive the group of practitioners.

Later, Wenger honed the description of the CoP to portray the three dimensions as *the domain*, which is the group's shared interest, commitment, and competence; *the community*, the member engagement in shared activities, discussion and information for the purpose of learning; *the practice*, which means the community is practitioners of some kind with a shared repertoire of "ideas, frameworks, tools, or documents" (Wenger-Trayner & Wenger-Trayner, 2015, Kezar et al., 2018, p.834). There are different types of CoP in education, and they take place in different educational arenas. For example, the joint enterprise of many of the articles referenced in this capstone is STEM reform. Regardless of the domain however, as Kezar et al. (2018) reflect, a core concept of CoP is their use of "community or social learning", and "interaction and relationships" (p.835).

Kezar et al. (2018) describes different forms of CoP that distinguish between faculty/higher ed and teachers/K-12. Higher ed CoP tend to form organically and be self-organizing, such as faculty learning communities, often organized around "instructional and curricular improvement" (p.835). K-12 CoP, called PLC (Professional Learning Communities), tend to be organized with intention and defined by leadership who involve members based on their roles, rather than purely interest in the "domain" (Kezar et al., 2018, p.6). Sometimes the

PLC are set up for teachers for them to develop as peers, but they are designed by administrators with specific purposes and agendas in mind. Servage (2008) suggests that the PLC bring teachers together to "engage in collaborative planning, curriculum study, and learning assessment" (p.64) and that it is defined by "shared decision-making…and dialogue" (p.64), but she describes this in relation to schools or school systems, not in wider spheres. Kezar et al. (2018) suggested that these differences in structure and function would lend themselves to further research to understand how these PLC can engage the process of transformational learning, and what the unique challenges and stages might be. For the purposes of this capstone, K-12 is examined as a CoP with unique features to help understand the perceptions of K-12 teachers as part of the Green Chemistry CoP, developed to support their needs.

Communities of Transformation

Communities of Transformation (CoT) are still CoP, but with a focus on influencing learning and changing practice (Kezar et al., 2018). The term was developed by Kezar et al. (2018) as they explored four CoP involved in STEM reform. They discovered that these four CoP and their behaviors could not fully be assessed with the original framework and definitions of CoP they had used to examine them with in the beginning. Instead, these behaviors could more thoroughly be explained using Mezirow's Transformational Learning Theory.

Mezirow (1997) described three phases that illustrated that learning had been transformational: a *disorienting experience/dilemma* occurs which causes the learner to look for new understanding (outside their usual CoP), the learner goes through *critical assessment/reflection* with the support and mentorship of the discovered community to unfold new learning, and then develops a *plan of action* based on the new understanding that addresses the dilemma they initially struggled with. Kezar et al. (2018) discovered that the large CoP they

were studying were actually undergoing these phases as they were working on STEM reform thereby creating Communities of Transformation (CoT) who will continue to influence the CoP they come in contact with while they continue to generate their own learning.

Supporting K-12

K-12 educators are widely known to be stretched thin with more and more responsibility being placed on them with regard to state tests, standards and student behavior. Depending on state requirements and grade level their formal education may not have fully prepared them to teach Science. Professional development courses offer continuing education to teachers and potential credit toward their professional teaching licensure providing further education in these content areas. In New York State, Cannon et al. (2023) describe a process whereby a state agency provided funding to an education organization to partner with Siena College faculty to develop professional development in Green Chemistry to high school and middle school teachers. The state agency recruited and funded teachers to attend the PD courses, drawing on their relationship with school districts. Administrators sent teachers for the training. Cannon et al. (2023) describe a process of faculty collaborating with these teachers, creating curriculum for and with them, sharing resources and providing green chemistry training and accompaniment.

When higher ed educators partner in providing PD, a level of expertise can be shared, providing training and curriculum support and resources to educators that districts may not otherwise be able to access easily. Teachers need “quality professional development [particularly in STEM content areas] to teach new concepts” (Cannon et al., 2023, p.2225). There are six federally defined criteria regarding this quality professional learning, according to the Every Student Succeeds Act (ESSA), as described by Cannon et al. (2023). It should be “sustained, intensive, collaborative, job-embedded, data-driven, and classroom-focused” (p.2225). Cannon et

al. (2023) included data on reports showing that over 80% of professional development fails to meet these criteria.

When faculty experts share in the creation of STEM courses and collaborate with teachers, encouraging their networking and collaboration with each other during the PD, supporting classroom efforts and maintaining a line of communication after the PD, several of the criteria are met for high quality PD. Burrows (2015) reflected similarly that K-12 teachers were more highly engaged in the "STEM content and partnership building during PD" (p.29), and that their perception around partnerships and collaboration also rose when they had the support of the higher ed faculty as well as the opportunity to learn with each other. Cannon et al. (2023) described how K-12 teachers were not only more likely to use green chemistry (a new concept) in their classrooms after the PD with the support of faculty and ongoing collaboration, but they developed a stronger sense of agency in themselves as Green Chemistry advocates, leading conference workshops and collaborating to develop curriculum guides for their peers. As Burrows (2015) concurs, when teachers have had strong systems of support with regard to developing partnerships and content, it is more likely that STEM will be implemented, that inquiry will be used in the lessons, that they will support their peers and develop a better sense of agency as a result of the collaboration with faculty on the PD development team.

Benefits to Higher Education

Higher ed CoP benefit when they collaborate with K-12 because as Foster et al. (2010) explains, these two communities bring different "attributes and work as co-learners and colleagues" (p.907). Foster et al. (2010) also gave an example of a Maryland state level partnership that discovered that teaching fellow programs and professional development workshops benefitted higher ed faculty by helping to achieve program goals and that the

relationships that were facilitated across the "K-16 spectrum (K-12, plus college or university)" were particularly beneficial to STEM faculty (p.906) because all of the educators (including K-12 teachers) were essentially in the same type of CoP, but sharing those interests across the entire education continuum increased their knowledge and effectiveness.

Foster et al. (2010) identified how instrumental the National Science Foundation's Math and Science Partnerships (NSF-MSPs) were in funding these higher ed and K-12 partnerships all over the country. While the purpose of NSF-MSPs was to "improve K-12 STEM learning," higher ed faculty have benefitted from "improved teaching skills, knowledge of K-12 education, and disciplinary research" (Foster et al., 2010, p.907). This partnership also provided funding and structure that influenced higher ed institutional culture, creating important faculty incentives for engagement. Tomanek (2017) reflects that graduate student fellows also benefit from the experience of collaboration and time in K-12 classrooms, similar to Foster et al.'s (2010) assertion that faculty's instruction is improved from increased awareness of student learning and deeper pedagogy understanding. These graduate fellows are learning from their K-12 classroom, where they increase their understanding of students and teaching, and bringing this learning to the classes they teach at the higher ed level (Tomanek, 2017).

Tomanek's (2017) exploration of successful K-12/higher ed partnerships also found that faculty benefit mostly when they ask, "how involvement with K-12 schools and teachers can enhance the education of their own students" and then apply what they learn from these collaborations into their own classrooms (p.29). Subramanian and Clark (2016) found that as faculty partnered with K-12 schools as well as industry, they were learning how to reduce "STEM attrition" that resulted from "lack of knowledge about the field" (Abstract paragraph) in both undergrad students and K-12 students. The El Paso MSP (one of those funded as an NSF-

MSP) worked with the University of Texas at El Paso toward a new tenure and promotion policy which benefitted faculty who partnered with K-12 educators (Subramanian & Clark, 2016, Case Study 2).

Challenges to Collaboration

Dolan and Tanner (2017) suggest that there are reforms to be made systemically in order for successful K-12 and higher ed collaborations to persist effectively. They argue that grant funding limits institutional ability to support collaborations and that "sustained infrastructure" needs to be in place to support long term engagement and programming versus trying to develop programming on a "grant-by-grant basis" (p.36). This infrastructure includes items such as "money and space, coordinated efforts across departments" (p.36) and shifts in mindset regarding partnership as just another community service to an understanding of their value in producing knowledge for all involved (Dolan & Tanner, 2017). Moreno (2017) and Zhang et al. (2021) further elaborated on these issues with regard to the need for better incentives for STEM faculty and adapting systemic processes, aligned with Dolan and Tanner's (2017) suggestion, that these should also include tenure and promotion.

These challenges can hinder collaboration. Foster et al. (2010) found that there were barriers to "community engaged partnership" (p.906) that came from academic practices involving attitudes and perspectives of institutions. These reflected the lower priority given to collaboration and the bureaucracy that hinders the process, which Zhang et al. (2021) reflected in their findings about the need for systemic changes in higher ed institutions in order to incentivize particularly STEM faculty to partner with K-12 educators. Zhang et al. (2021) specifically suggested incentives such as release time and stipends for faculty as well as opportunities for professional development to prepare them for this collaboration.

Challenges Due to Differences of CoP

Elgin et al. (2017) found that there were challenges based on the differences in K-12 versus higher ed scheduling and calendars, and that faculty had to figure out how to work within the challenges and constraints of K-12 funding, often needing to provide the funding themselves in order to complete the collaboration. Moreno (2017) expounds on "pitfalls of partnerships" such as K-12 schools not having minimal resources in place for science instruction, or not giving the same priority to science education, and the "mismatch between professional practices of scientists and teachers" (p.31) that cause misunderstandings between them, due to "work environments that encourage different kinds of behaviors and require different kinds of knowledge" (p.31). Moreno (2017) points out that while scientists expect to find equipment naturally available in schools and can be disappointed at the lack thereof, teachers may be offended or intimidated with the way scientists ask questions.

Moreno (2017) further elaborates that at times K-12 schools don't have the same priorities and don't give the partnership the same priority. This can be due to funding but may also be due to the challenges of "not having time to create a professional learning culture in schools" due to other demands. Another issue Dolan and Tanner (2017) unfold is the need to shift from a "provider-recipient model" to one of mutual learning between faculty and teachers, and that teachers must be willing and able to "share their expertise about teaching science and scientists must adopt a learning stance" (p.35). Dolan and Tanner (2017) and Burrows (2015) found issues with K-12 teacher confidence in their own expertise which at times hindered collaboration from being a two way street and which also impacted teacher hesitancy to reach out to higher ed faculty.

Theoretical Framework

The theoretical frameworks used for this capstone include Mezirow's (1997) Transformational Learning Theory (TLT), particularly in its use by Kezar et al. (2018) with regard to CoT, and Jean Lave and Etienne Wenger's Communities of Practice (CoP) framework, based on Wenger's (1998) additional applications and Wenger-Trayner and Wenger-Trayner (2015) updates developed in partnership with his research collaborator and spouse Beverly Wenger-Trayner. TLT was used particularly as a lens to understand the Beyond Benign team's understanding of their roles and vision as part of a CoT, and also with regard to how K-12 educators saw their understanding and practice transform as new learners in the Green Chemistry community, interacting with Beyond Benign. The CoP framework was used as a lens for understanding K-12 teacher experience during their collaboration with Beyond Benign and its higher ed partners.

The TLT theory, in this case, references a new variant of communities of practice (CoP), that happens when "innovative spaces are created and fostered, envisioning a new future" (Kezar et al., 2018, p.832). Mezirow (1991, as cited by Kezar et al., 2018) theorized that transformational learning happens when a change of consciousness occurs, which is different than simply acquiring skills and knowledge. According to Kezar et al. (2018), CoP that experience this type of transformational learning or are impacted by it undergo a change in consciousness or values through a collaborative process of accompaniment or mentorship to become CoT.

Mezirow (1997) noted three stages that occur in TLT: first, a *disorienting dilemma/experience* occurs that causes the learner to experience dissatisfaction with the understanding they have had, or in Kezar et al.'s (2018) example, dissatisfaction with the CoP

one is involved with or the operation thereof; second, the dilemma causes the learner to have discussions with others, or maybe they were influenced by another view or CoP with a unique perspective causing *critical assessment.* This questioning of the current reality happens through the influence, collaboration and support of another CoP in Kezar et al.'s (2018) example; third, a *plan of action* is developed through the support of others who help the learner through mentorship to put their learning into action (Mezirow, 1997). In Kezar et al.'s (2018) process this can happen to a whole CoP, where a member is influenced by another CoP who is advancing their learning and joins that CoP who are becoming a CoT through the process of new learning and practice, or the influenced CoP member takes the new learning back to the original CoP and helps drive that CoP to become a CoT. In these cases, whole CoP are engaging the transformational learning dynamic to become something new.

Jean Lave and Etienne Wenger introduced the Community of Practice (CoP) framework as a means for understanding how these communities developed and why. Wenger (1998) describes CoP as "communities through which individuals develop and share the capacity to create and use knowledge…through participation with people…whom they interact on a regular basis [with]" (p.2). These people can be informally bound across different groups and networks, but they share three important aspects as a CoP, according to Wenger (1998): *joint enterprise* which is what they are about, or the participants common purpose and shared goals, the sense of community, which is "continually renegotiated by its members" (p.3), which Wenger-Trayner and Wenger-Trayner (2015) currently describe as having a *domain*; *mutual engagement* which looks at the function that connects them over mutually agreed upon subjects; and *shared repertoire* or the development of shared language, tools and resources and other capabilities in their collaboration as a community over time, which Wenger-Trayner and Wenger-Trayner

(2015) label as *shared set of practices*. Wenger (1998) describes how these CoP develop around "things that matter to people" and are "self-organizing systems" moving according to the community's ideas (p.2)

Beyond Benign and Green Chemistry CoP

Beyond Benign is a Green Chemistry education organization. Their mission is to "foster a green chemistry community that empowers educators to transform chemistry education for a sustainable future" (Beyond Benign, n.d.). They do this by working with higher ed and K-12 educators as well as industry leaders to create a CoP that is creating advocates in many spaces to spread the practice of Green Chemistry and to invite more educators into the CoP. The more informed educators there are the better prepared that students will be to go from K-12 into STEM fields with an understanding of how to apply Green Chemistry to their fields, and the better prepared the higher ed students will be to enter industry as Green Chemistry practitioners and innovators, implementing their understanding of these sustainable practices to create real and lasting change in the world.

Beyond Benign is leading this community because the founder and executive director is the first graduate in the world to receive her PhD in Green Chemistry, and her husband, the co-founder, is considered to be one of the fathers of Green Chemistry as it is practiced today. They decided to work with K-12 teachers at the start of the organization because if you train a teacher, you educate thousands of students. They are also training faculty for the same reasons and are now working with higher ed institutions globally to sign the Green Chemistry Commitment, which enlists institutions and educators in whole department transition to sustainable practice.

Another aspect of their strategy to engage educators in the Green Chemistry community is the development of a community building virtual platform called the Green Chemistry

Teaching and Learning Community (GCTLC). This newly developed platform engages science educators in collaboration, which initially is uploading and sharing of resources, but is evolving as participants begin connecting with each other and engaging over the resources. Partnerships have already begun to unfold there even after only being established for less than six months.

As Beyond Benign continues to be instrumental in fostering Green Chemistry education in both K-12 and higher ed CoP it seems fitting that the next step is to find a way to bring these CoP together in meaningful ways. It also makes sense to find a better way to fund and support the K-12 program after so many changes and challenges in the last few years. As Beyond Benign thinks of its work as fostering CoT, it will be helpful to include examination of its internal and external practices and to explore what it is truly capable of as this wider community continues to expand and grow. It has to ask the question of how to grow with the changes in the CoP it is a part of, and also whether it is time to focus in one CoP or another to be effective in its collaborations, allowing for others to rise up and provide support where it may no longer be able to do so effectively.

Capstone

Through an exploration of the Green Chemistry Communities of Practice supported by Beyond Benign, particularly those involving the K12 CoP and higher ed CoP, this capstone project aims to capture the dynamics, challenges, and opportunities inherent in this collaboration. By leveraging insights from diverse stakeholders within the CoP, this study seeks to identify best practices for strategic planning to enhance the effectiveness and sustainability of continuing to support and develop the K-12 CoP specifically, given the limitation of its resources and its evolved path of focusing primarily on the higher ed CoP.

Methodology

The goal of this strategic plan was to explore new possibilities for Beyond Benign's K-12 program, to bring it into alignment with the organization's evolving mission as community builders in a Green Chemistry Community of Transformation, potentially through the collaboration of the higher ed program, and to offer recommendations as to how these communities may collaborate from their engagement. As both communities of practice evolve around their own missions, it is hoped that the places where they overlap will be areas that enable both communities to coalesce around commonalities and that they are able to learn from each other and support each other in collaborations.

This capstone utilized a qualitative approach to address the exploration of past partnerships between these two communities which were facilitated by Beyond Benign. This was done through stakeholder interviews that include current and former team members, K-12 educators, and higher ed educators.

Organization of Focus

"Beyond Benign is a leader in green chemistry education" (Nahlik et al., 2023, p. 287), co-founded by Amy Cannon, PhD and John Warner, PhD in 2007. They are "dedicated to fostering a green chemistry community that empowers educators to transform chemistry education for a sustainable future" (Beyond Benign, 2024, Building a Community of Transformation, paragraph 1). They initially worked with middle and high school teachers to establish green chemistry curriculum globally, until 2013 when the Green Chemistry Commitment (GCC) program was launched, bringing higher ed more officially into the process. In 2016 the Lead Teacher Program was developed in North America to foster the development of K-12 teachers. This program was started collaboratively by a group of teachers and Beyond

Benign staff to "help train educators in principles of green chemistry and empower them to share that expertise with other teachers" (Nahlik et al., 2023, p. 287). It engaged teachers in a three-year, stipend contract. This program was funded through a million-dollar grant, which was not renewed. The last cohort of teachers will finish in May of 2024. Currently there is no K-12 director or program manager, or funding for K-12 beyond a small New York State Pollution and Prevention Institution grant, and some general funding that covers small portions of K-12 needs from Argosy, a foundational funder for Beyond Benign.

The GCC program that engages higher ed institutions in committing to green chemistry practices and enables them to apply for grants and other benefits has been the flagship program for higher ed engagement, along with webinars and conferences. Currently, K-12 still has three online professional development courses offered annually, taught by current and certified Lead Teachers; and it also has a monthly webinar, Observe Wonder Think, where Lead Teachers and other K-12 educators come together to interact around educator and practitioner presentations.

One of Beyond Benign's main focuses has been to develop and launch the Green Chemistry Teaching and Learning Community platform (GCTLC) to engage the GCCoP in collaboration and community building around green chemistry education. It is a joint venture between Beyond Benign and the ACS Green Chemistry Institute. It is meant to be "by the community, for the community" (Beyond Benign, 2024, About the GCTLC, paragraph 1), a place where educators can connect, collaborate, share resources, network and find mentorship. This space is also meant to bring the entire community together, including K-12, higher ed and industry professionals, the collaborators that will bring about the CoT.

Strategic Plan Goals

The goals of this strategic plan were to explore the following questions:

- How do the Beyond Benign team and K-12 teachers see themselves as part of the GCCoP?
- How can Beyond Benign bring the K-12 program into alignment with the organization's evolving mission?
- What are some ways that the K-12 and Higher Ed communities may improve their collaboration and engagement, creating new possibilities for K-12, and bringing the two communities back into one evolving GCCoP?

This was partially achieved through exploring transformational learning/CoT variables, such as *disorienting dilemma/experiences,* around the team's assumptions as they joined Beyond Benign, and what they are actually discovering as they do the work; *critical reflection/assessment,* around what they are discovering through collaboration, as well as their perceptions around mentorship, collaboration and support; and *planning a course of action,* which delves further into the understanding of vision/mission and the nature of community building as a team in each role, and leads to new understanding and consciousness as the collaboration and support unfold (Mezirow, 1997).

Materials

Interview questions for Beyond Benign team members were developed around Mezirow's (1997) Transformational Learning Theory (TLT) to discover perceptions that the team members have of themselves as a CoT and to discover their perceptions of the K-12 CoP as part of that CoT. Interview questions for educational partners were developed utilizing Jean Lave and Etienne Wenger's framework on Communities of Practice (CoP), as described by Wenger

(1998), in order to explore the perceptions that collaborators have of themselves as a CoP and also to discover strengths and challenges of K-12/higher ed partnerships. Questions developed from this framework centered on the variables of *mutual engagement*, and how collaboration was perceived; whether collaborators felt and continue to feel a sense of *joint enterprise*, during collaboration with Beyond Benign, higher ed partners, K-12 educators; whether collaborators engage in a *shared repertoire*, with recognized language, tools, etc. that are shared by the CoP (Wenger, 1998). See interview protocols in Appendix A.

Procedure

Participants were selected based on discussions with the Beyond Benign team and personal experience working in collaboration with them. They were invited via direct email, or introductory email from team members, to participate in an interview about their collaboration with the GCCoP, Beyond Benign specifically, and also between groups. Once participants confirmed, they were sent a calendar invitation for 30–60-minute interviews that included their questions for an interview session. At the time of the interview, participants were asked questions from the interview protocol (Appendix A), according to their category of participation in the CoP. Feedback was recorded using Zoom's transcription tool. Once the meeting was over, participants were thanked for their time. The data was then transcribed into a Microsoft Word Doc. Data was then placed accordingly into participation and question categories, already separated by variables that define CoP or CoT. The categories were then analyzed for themes.

These results were analyzed, across three groups of collaborators: Beyond Benign team members, K-12 teachers, and higher ed faculty. These responses were analyzed utilizing the variables that define CoP (Domain/mutual engagement, Community/joint enterprise, and Practice/shared repertoire) and the variables that suggest transformational learning that occurs in

a CoT and patterns compared with current research articles, curated with regard to STEM partnerships between K-12 and higher ed and transformational learning in CoP that enabled them to become CoT. These methods were executed to discover how the collaborative learning may have transformed understanding and practice both in the Beyond Benign team and in the CoP that includes K12 educators primarily, but also their higher ed collaborators, what knowledge was generated during the collaborations, what challenges were overcome, and what stakeholders found to be replicable and sustainable that might be used to generate new collaborative partnerships in the combined Beyond Benign community of K-12/higher ed educators.

Results

Perceptions and Involvement in the Community of Practice (CoP)

All nine (9) members of the Beyond Benign team (respondents B1-B9) were interviewed individually, which included the Executive Director, the Chief Operations Officer, Higher Ed team, GCTLC team, Finance Officer, Communications and Events Coordinator and the Content Manager. All but three of these (B2, B3, B8) are PhD chemists. All nine members reflected that they saw themselves as part of the GCCoP, although some suggested that they were not fully a part of the wider CoP because they were neither a green chemist nor an educator. A few members were not sure until interviewer defined the term, but then acknowledged that they were a part of it.

Six (6) K-12 teachers (respondents T1-T6) were interviewed either individually or in focus groups of 2-3, including the three current Lead Teachers (LTs) and three Certified Lead Teachers (CLTs). Four were high school chemistry teachers. One was a middle school science teacher. One was an elementary teacher. All teachers were women. One was retired from teaching, but still actively participating in the CoP as a connector of other teachers to the CoP.

Two were women of color. They all saw themselves as part of the CoP. Two saw themselves as part of it mostly through their connection to Beyond Benign, but four saw themselves as connected to the CoP additionally through connections to higher ed partners. One saw themselves additionally connected through partnership with industry, although the partnership was facilitated by Beyond Benign.

Two (2) higher ed faculty (respondents H1-H2) were interviewed, although they were not directly questioned about their perceptions regarding participation in a CoP. Both interviews were done collaboratively as a focus group with two additional Beyond Benign team members. Both faculty members were men. H1 worked with many of Beyond Benign's LTs and was instrumental in channeling them into working with Beyond Benign. H2 worked mainly with students as a mentor and collaborated with their teacher. H1 and H2 were asked about their collaborations with K-12 teachers and their learning from this engagement, including the successes and challenges. Even though not asked specific questions about the GCCoP, H1 described elements of *domain/joint enterprise, community/mutual engagement,* and *practice/shared repertoire* that reflected his perceptions regarding his participation in it.

Domain and Joint Enterprise

The Beyond Benign team (B1-B9) was asked questions about their thoughts and beliefs on participating in a CoP regarding a sense of *domain and joint enterprise.* This included questions about their evolving understanding as they participated in their team role, the learning they experienced and how they saw themselves growing through the process. All nine members, including the executive director, regardless of the length of time they were on the team (3 months-14 years), reported experiencing a shift in their role once collaboration began unfolding or the need to shift to fill a need on the team occurred. At least four members of the team (B1,

B7, B8, B9) reported experiencing dramatic shifts in these roles as the organization shifted to a completely virtual organization, and as it shifted to accommodate educator needs during and after the pandemic. B1, B3 and B9 all discussed the domain with regard to the evolving DEBR (Diversity Equity Belonging and Respect) policy and how that has impacted the organization's focus in meaningful ways.

Teachers (T1-T6) were also asked about their sense of *domain and joint enterprise* with regard to being part of a CoP. All six teachers needed definitions for what a CoP was, but then described the ways that this engagement occurred, such as having the common goal of educating students and preparing them to be more engaged and knowledgeable scientists and preparing them to engage the world with a green chemistry lens focused on sustainability. Three of the teachers (TT1, T2, T4) are CLTs that still participate as instructors for Beyond Benign online courses or have continued collaboration with faculty partners outside of Beyond Benign, or both. Three of the teachers (T3, T5, T6) are current LTs and are engaged in multiple collaborations with each other and Beyond Benign team members.

Higher ed partners (H1-H2) were not asked about *domain and joint enterprise* directly but described the common goals of educating teachers and students in green chemistry/sustainable practices as well as what they had done to achieve that end during collaboration with either high school students or K-12 teachers. H1 described commitment to the GCCoP regarding his roles and his plans for further collaboration with K-12 educators and students. H1 and H2 described several challenges to K-12 collaboration that included funding, tenure track, access to R1 and R2 professors, creating value for higher ed faculty to collaborate with K-12 teachers, having time to dedicate to the process of collaboration on their side, and recognizing the challenge of finding time on the K-12 side.

Community and Mutual Engagement

The Beyond Benign team members (B1-B9) all described a great deal of interaction with *community and mutual engagement.* They each described clear ways that the CoP functioned and their individual roles in that process. They had varying descriptions of perceived importance of their roles in the process based on whether or not they were engaging the community as green chemistry educators. They were all very clear as to the purpose of the shared activities such as the GCTLC, conferences, webinars, newsletters, and developing learning spaces for educators.

The K-12 teachers (T1-T6) described their understanding of *community and mutual engagement* mostly around the Lead Teacher Program (LTP), teaching or participating in online courses, or attending OWT webinars. Five of the teachers (all but T3) additionally described this with regard to higher ed collaborations. Three (T3, T5, T6) expressed concerns about the Lead Teacher Program (LTP) ending this year and also described fear about the uncertainty of how community would look for them afterward. One CLT (T2) expressed concern that a college partner was retiring and what that meant for her participation in the wider CoP. One LT (T5) expressed concern regarding a transition that may not be as supported without a concrete involvement in the CoP.

Higher Ed faculty (H1-H2) were not asked about *community and mutual engagement* but described the group function and social connection of being connected to K-12 teachers they had collaborated with, providing PD or facilitating connection to Beyond Benign programs. H1 still exchanges emails with former K-12 collaborators, answering questions regarding labs and referring the teacher to additional resources. H2 reported frustration with connecting students and teachers to other faculty, particularly in research facilities, but remains as a resource to these K-12 educators and students.

Practice and Shared Repertoire

Beyond Benign team members (B1- B9) reported a great deal of *practice and shared repertoire*. They each described the resources they were involved with either developing, sharing with collaborators, creating for dissemination. They also described the collaborative nature of team meetings, newsletters, Microsoft Teams files, Microsoft Teams chats, the GCTLC development and usage.

The K-12 teachers (T1-T6) described *practice and shared repertoire* around the development of labs, resource guides, lesson plans and courses. T6 described the way several colleges shared lab kits with her elementary classroom. T1, T2 and T3 described creating lab kits for home use during the pandemic for distribution to homes of students. T1 also included students in the process of creating resources. T4 has brought students into the CoP by having them develop lessons and labs to present to younger students. This CLT creates videos of these lessons (both hers and the students) to be shared on YouTube and also on the GCTLC to share with other GCCoP educators.

The higher ed faculty (H1-H2) describe *practice and shared repertoire* around resources that they developed in collaboration with K-12 teachers. H1 collaborated on a lab book with K-12 teachers from elementary, middle and high school as an OER, to share on the GCTLC and has collaborated with other faculty, and Beyond Benign team members to write an article about the green chemistry process unfolding in his state. H2 reported facilitating the research process of students through discussions of the higher ed research process, fostering an understanding of research vernacular, and introducing students to websites and helping them use them to hone their understanding of the research process.

Communities of Transformation

Beyond Benign team members were the only ones familiar with the term community of transformation, and they were not all completely sure what the difference was between a CoP and a CoT until it was discussed in the interview. B1 described the CoT best and said that it is a goal the organization is striving toward, not something that they have declared that they are. All nine team members expressed great expectations for the GCTLC and its role in helping to bring together the GCCoP for the purpose of evolving a greater GCCoT. Six of the team members (B1, B4-B7, and B9) have roles as facilitators in growing and educating the GCCoP through their green chemistry research, facilitation of webinars, production of newsletters, social media posting, presentation at conferences and as advocates and promoters of the GCC (Green Chemistry Commitment) and the GCTLC. B2, B3 and B8 support this process via collecting data and planning events and coordinating communications, as well as operations and development. All nine team members describe their roles evolving as learning occurs and needs arise that suit either their roles or their talents.

Each team member (B1-B9) described each program as part of their own collaborative efforts and as vital to the process of the whole organization. Each team member (B1-B9) described the philosophy of green chemistry as integral to both their role and their belief about the world and the GCCoP, and also described what the organization does as something they came to deeply appreciate and believe in through either their PhD work (B1, B4-B7, B9) or through their association with Beyond Benign team members before working there or as they onboarded and developed a deeper understanding of the vision and mission (B2, B3, B8).

Discussion

Interviewing Beyond Benign's collaborators regarding their perceptions of being involved in a CoP enabled an expanded exploration of the K-12 program, its overall connection to the mission and vision, and its potential to adapt and be revised with this dynamic CoP. These interviews also allowed for an exploration of Beyond Benign as a CoT, and how that is working in practice with the three groups of collaborators.

The Beyond Benign Team Perceptions of CoP and Transformation

All nine members of the Beyond Benign team (B1-B9) described themselves as being part of a CoP. The way they spoke about the science and practice of green chemistry was much like a philosophy that they deeply believed in. Most of the team's roles have changed as they signed on and the collaboration and growth dictated that they either shift roles to stay in pace with the growth or that they needed to take on additional functions to enhance the collaboration. B1 talked about her role shifting from being part of the direct training of K-12 teachers and higher ed faculty, running each program, to accompanying others to run these programs so she could shift into more leadership roles and higher-level collaborative roles with organizations and institutions. B7, B8, and B9 all spoke about coming on to help with either higher ed or development aspects but supporting the K-12 program too. "Everyone did everything…and I would help with all the set up and support of the K-12 program, and the K-12 director and program manager would do the same for higher ed trainings" (B7 interview). Those same team members suggested that at the time when they all came on (within 1-2 years of each other), the organization was very focused on the K-12 program, with the LTP in full swing, many in-person trainings in different states, and a very large grant that sustained that work over several years. These respondents also described the excitement witnessing the transformational learning

process of K-12 teachers, often in person as they were part of the support team. They described the K-12 and higher ed program as two parts of one whole. These respondents described two of the distinctive characteristics of a CoT via Kezar et al.'s (2018) designation of "creating and fostering transformative learning" and a philosophy that is "central to their community adhesion, engagement, action, and learning" (p.853).

These ideas were then applied to the higher ed CoP, and that program began to take off both virtually and in-person. B1 stated "we became a bunch of chemists doing community building" (B1 interview), and B7 described "going from a community that is practicing and thinking about what they're doing to a community that is truly sharing and distributing and taking what works at one institution and sharing it with another institution [through the GCC program]" (B7 interview).

As higher ed began to take off it was easier to develop funding for this program, according to B1 and B8. Also, the pandemic impacted K-12 in deep and lasting ways, including the need to be virtual for two years. The major funder pulled back funding for the LTP. These big changes resulted in the K-12 team members leaving within months of each other, which further resulted in a rudderless program where other team members stepped in to keep the LTP going. Because of the strong sense of domain and community present at Beyond Benign, team members supported where they were able, but it put a large strain on the designated roles of team members in an organization that was still growing quickly in its mission to build green chemistry community globally. This reflects Kezar et al.'s (2018) third distinction between a CoP and CoT, "transformation of practice rather than focusing on the impact/outcomes" (p.834) and "relying on the philosophy to define the domain more than existing practice" (p.853).

More recent team members also reported their sense of being part of a CoP. B3 and B5 discussed finding Beyond Benign in college and being very excited about the possibility of using chemistry as a means to solve problems of climate change and other sustainability issues. B4 led a green chemistry student organization on campus before joining Beyond Benign as a team member. Environmental justice was the reason that B3 and B9 gave for their participation in the GCCoP. Both of these respondents spoke about the issue in terms of generating wider participation, creating opportunities for people who were the most impacted and vulnerable to the impact of environmental injustice.

B8 described how exciting and unusual it is to work with an organization that is always planning with the community they are collaborating with. This team member spoke about how everything is started with that process, including the GCTLC, "making sure that the community members are engaged from the ground up through collaboration, creating advisory groups that include collaborators, team members, educators (K-12 and higher ed)" (B8 interview), and how it may take much longer to produce materials, "some organizations write curriculum in months, and ours could take years because it takes a long time to bring people together and to get them to coalesce around an idea… so as we think about the work we're doing and what we're committing to building, we make sure we build in enough time to get that group formation and idea sharing into the process" (B8 interview). B8 described the process of sharing back and forth with the community to get feedback, piloting programs and curriculum, incorporating the feedback and repeating the process so that there is "a lot of value then when we roll something out. We have ambassadors, people that have done the work, who then share it with others, so we are staying true to our goal of by the community for the community" (B8 interview). B1, B9 and B8 specifically spoke of amplifying the voices of chemists of color and MSIs (Minority Serving

Institutions) and the effort that it takes to build the relationships that started out smaller without much understanding of how to do this and have grown over time in both the K-12 and higher ed spaces.

All nine team members expressed an understanding of the value of the K-12 program and a desire to see it reinvented or brought back to life if possible. When they spoke about the common goals of the GCCoP, they included K-12 in the vision to empower all educators to teach green chemistry: “Third grade, eighth grade, high school, graduate school, you know, educators all have that ability to inspire, excite, teach, train students, which is the only way we’ll achieve our vision of having safer chemical building blocks produced in the world” (B8 interview). B4 said, “I think [K-12 curriculum/programs] gets students excited…prepares them to think critically about where stuff goes, where it comes from…what is safe or not…creates informed and literate citizens, regardless of career path” (B4 interview). B7 reflected that “if we had a strong K-12 program it would only make the higher ed GCC program grow because the students would hear about green chemistry earlier because teachers would be talking about it in high school” (B7 interview) and that Beyond Benign founders have stated that “if we don’t get students’ attention in science by the time they’re 8 years old, you’ve lost them” (B1, B5, B6, B7, B9 interviews).

These views are in line with Cannon et al. (2023) and Nahlik et al. (2023) findings around K-12 teacher education, “we want to prepare conscious citizens and not just scientists” (Nahlik et al., 2023, p.290), and the idea of scientific literacy being paired with good collaboration. Cannon et al. (2023) acknowledged that for every student to succeed as per federal program guidelines, there must be high quality professional learning that meet the standards of criteria for teachers’ professional development.

Beyond Benign team members described their organization as having the most impact by building community in the GCCoP, continuing to build a network of green chemistry educators who wish to collaborate with and learn from each other along the K-20 pipeline of education. B7 described "creating a community that truly feels connected and engaged around people…we hold space for people, and they recognize that we are trying to create space intentionally, that it's open access, there's no pay wall, or membership requirement to collaborate" (B7 interview). B8 reflected that there are many opportunities as a community building organization to "enable educators to do the work they want to do…support cross university work, break down silos between faculty and K-12, share DEBR training for K-12 educators…helping educators realize that they can do both STEM and DEBR at the same time very effectively with us" (B8 interview). B1 reflected on the value of being an organization that is supporting education outside of the education system, "being able to work with multiple universities and organizations, not just one system, trying to catalyze change from outside the system…we can be that outside force that's helping to bring people together, and be that community connections piece, I feel like *that* is our role" (B1 interview). The way that the Beyond Benign team sees their impact on the GCCoP is very much the way Kezar et al. (2018) describes "fostering innovative spaces that envision and embody a new paradigm of practice" (p.833).

K-12 Teacher Perceptions of CoP

All six (T1-6) respondents described themselves as participating in the GCCoP with Beyond Benign, and all but respondent T3 reported having regular contact and collaboration with higher ed faculty that they considered to be more widely a part of the GCCoP. Respondent T3 has collaborated with faculty in developing K-12 resources but expressed a desire to find someone in her region to more closely collaborate with, whether it be higher ed faculty or peers

in K-12. The type of higher ed collaboration cited by the other respondents include, PD, research, article writing and publication, lab lesson development and support, classroom support, classroom lab closet safety assessment, and general discussion with these partners, giving them access to further support and accompaniment via phone calls and emails as needed. This suggests, as both Kezar et al. (2018) and Wenger-Trayner and Wenger-Trayner (2015) note regarding common goals of a joint enterprise and practice that includes a shared repertoire of language, materials, resources, that the T1-6 respondents all see themselves clearly as collaborators in the GCCoP.

The teacher respondents all reported seeing themselves as being accompanied through green chemistry education by Beyond Benign and encouraged to develop their capacity through PD courses, in-person and virtual collaboration with peers and Beyond Benign team, including the expertise of its chemists. All six respondents spoke about the overall mission of the CoP as vital to their own classroom practices and described themselves as practicing common goals together in and out of the specific Beyond Benign programs, speaking to the concept of mutual engagement/community that Wenger-Trayner and Wenger-Trayner (2015) describe as defining a CoP. These responses also reflect the stronger sense of agency through accompaniment that Burrows (2015) and Cannon et al. (2023) found in their research.

Respondent T2 is a CLT and continues to participate directly with Beyond Benign, even after the LT contract ended years ago. T2 teaches one of the online K-12 PD courses Beyond Benign offers and says that this role is vital in keeping her connected to the CoP. Respondents T1 and T3 similarly teach Beyond Benign online K-12 PD courses. They say that they see how important it is to help other teachers enter the green chemistry space and shift their understanding of sustainability. T2 acknowledges that this is “so much of our

mission…providing accessibility to green chemistry and exposure…just to get them excited and interested to pursue more learning" (T2 interview). The LTs/CLTs all expressed the desire to bring teachers and/or students into the GCCoP through conferences, webinars, OER, PLTs (Professional Learning Team, a variety of a PLC), PD online courses, and peer-to-peer discussions and training.

T1, who is also a CLT and now retired from teaching high school, reflected how important it has been for her to connect educators to the community, "sharing resources and best practices" in conferences, webinars and the state GCPLT (Green Chemistry Professional Learning Team) for K-12 teachers that she has facilitated. All six of the teachers (T1-6) have presented at Observe Wonder Think, a K-12 interactive monthly webinar, where K-12 educators and occasionally higher ed faculty or industry leaders present best practices for the lab and classroom. All six (T1-6) have collaboratively created labs and shared them as OER (Open Educational Resources). Like Blomgren (2018) notes, the process of developing resources collaboratively for the purpose of helping peers helps educators become more collaborative, adaptive and inclusive.

The respondents (T1-6) spoke of feeling very supported by Beyond Benign, and T2, T4 and T6 additionally described a feeling of being supported by higher ed faculty partners during specific and/or ongoing collaborations. T6, as an elementary educator, described having to convince higher ed faculty and/or programs that had kits or programs designed for middle and high school to support her as an elementary teacher, sharing the resources to her and her classroom. She said that even though it tired her out to always have to fight to have her level included, it was worth it because she got to bring green chemistry to her fifth graders. She reported that one of the universities was so amazed at what she sent them as evidence of what

elementary students are capable as far as green chemistry and lab engagement that they want to do a report on her classroom. T6's examples are representative of the way that members who are influenced by the advanced learning from participating in a CoT often become influential in spreading these practices when they take it to other CoP and become drivers of their learning (Kezar et al, 2018).

Each respondent (T1-6) spoke of the high value of the peer-to-peer collaboration and the mentoring that Beyond Benign provided, as well as the PD courses, through its Lead Teacher Program (LTP). They described these experiences as transformative with regard to their classroom practice as well as the way that they engaged with chemistry. Three of the participants (T1, T4, T5) had chemistry background before participating in the LTP and described the green chemistry education and support of the GCCoP as transformational to their understanding and practice of chemistry as both chemists and educators. Three of the participants had no background in chemistry (T2, T3, T6), however they did have background in biology and some science education and became excited about the possibilities for their students through green chemistry education and shared how it impacted their ability to create safer classrooms, engage students in looking at real world and relatable problems and solutions through science. T2 spoke of being given the tools to "analyze some of these 'store-bought curriculums' with a tougher lens and adapt it in a greener way, especially for classroom safety" (T2 Interview).

While all six (T1-6) described how accessible Beyond Benign team members were as collaborators, and how willing they were to support the teachers, and how they came to realize their own expertise through collaborating with and being offered opportunities to present by Beyond Benign, they reflected that this process had also made them aware of areas that could be improved or areas they were worried about once the LTP ended in 2024. T5 and T6 described a

concern over the lack of structure they would have as collaborators once the LTP ended, citing things such as "the structure was nice to…have in front of you, knowing what you needed to accomplish and get done. Without that, you're just kind of, I don't know, moseying along" (T6 Interview). T5 suggested that she is worried about not having the direct support through program involvement while she is going through a major transition at her school. T1 acknowledged that while she knows she always has the support, she is concerned that she doesn't have something solid to invite new teachers interested in green chemistry to be involved in. T3 would really like more collaborators from her state, especially higher ed collaboration "in order to get things going here, it's surprising to me that there aren't more people interested in green chemistry, and I could use more support in getting something going here." T2 suggested that finding time to stay involved is really a challenge and that her online course instruction and university collaboration were vital to her staying involved in the wider GCCoP. T4 wants to have more vertical alignment discussions with higher ed faculty and engage in more higher ed faculty spaces to learn what is important to them in this GCCoP and find connections for collaboration with those faculty.

Two of the respondents (T4, T6) described transformational practices for themselves and their classroom in great detail, particularly in line with Kezar et al.'s (2018) description of a CoT. Their classrooms are like mini CoT where the teacher is fostering the students' ability to engage in a well-defined green chemistry perspective, embodying these practices as learners, bringing their lived experience into the classroom and examining the practices of the world around them through the critical lens of this perspective, "grounding [students] in a paradigm-altering value system, guiding novel behavior" (Kezar et al., 2018, p.843), and creating a sense of agency in their students.

One respondent (T1) described the transformation that had occurred before she retired from her classroom, especially during the pandemic, and how she uses this experience to bring other teachers into the GCCoP. She shared how the virtual component of teaching presented an incredible barrier to the lab sciences and teaching. She was able to engage students in creating home lab kits with her due to the safety of green chemistry ingredients (most of which can be found in the home and used for cooking or simple cleaning) and got the same bus that was delivering food to deliver her lab kits to students. She was able to do three quarters of her curriculum that year, including labs, when most teachers could not do any of it. She described kitchen chemistry lessons where students were even invited to call their younger siblings in to participate. She created community and agency around the process.

T4 spoke first about the transformation that she had gone through as a student chemist and learner, working as a chemist and an intern at first. She described the learning process as one that shifted her perspective about chemistry first and then, helped her see herself as an educator through the process of supporting other educators and then eventually entering the LTP as an educator herself "tapping into the GCCoP, seeing myself being an active member of this green chemistry educated community for the rest of my life" (T4 Interview). The way she talks about her classroom is as a place of transformation for students and herself.

She describes teaching them how to be agents of change, examining issues that cross race, gender, sexuality and science as issues that are relevant to all of us, regardless of the social location we reside in. "I draw them in, posing essential questions at the beginning of each year. We label ourselves green chemists in our classroom space. So, questions center around our thinking, how we do things as green chemists, how do we as green chemists create safe materials? And that kind of calls them in to be like, I've got to think of myself as a green

chemist" (T4 Interview). This reflects Kezar et al.'s (2018) definition of CoT where "communities create and foster innovative spaces that envision and embody a new paradigm of practice" (p.833).

She has students look at the world around them, including the things they consume daily in their own lives. She has them examine the risk of chemicals to health and how particular populations may be more impacted than others and then has them come up with solutions. One of the higher ed faculty collaborations T4 participated in was around social justice and personal care products. Her students became educated in not only discovering that the products designed for them were dangerous, but then problem-solving creatively to come up with solutions. They created their own hair care and skin products, in this case designed specifically for women of color, in their school lab. The students were then empowered to present their findings and their solutions to their peers. And recently her high school students were asked to present to a group of educators at Observe Wonder Think for the work they were doing with elementary school students around helping them develop more sustainable and less toxic paint and crayons. T4's practices also align with the concept of vertical alignment as described by Burrows et al. (2014) where concepts are not only built upon but incorporate real world problems and incorporate the element of problem-solving.

T6 described a CoT-like environment in her elementary school classroom where she invites students to learn about green chemistry and its sustainable impact, often through the environment and labs that she obtains from four different colleges. She had students questioning the air quality of their classroom during the pandemic, examining the chemicals in hand sanitizers, exploring how to improve the air quality through a variety of experiments, and thinking about the chemicals that were present in their foods.

This teacher had collaborated with a well-known corporation that creates vegetarian versions of meat such as burgers to create an elementary and middle school curriculum around food and used it with her students to examine their diets, both in and out of school. The students lived near important water ways and explored things that were polluting them and what they could do about it. They became very concerned about the vape pens that littered these waters and what the chemicals from them would do so the teacher ordered a tetrahymena lab, which contained the chemicals from the vape pens and the single celled tetrahymena. In these hands-on labs, the students were able to see for themselves what the effects of vaping chemicals were on lung cells, "way better than any drug program can do because they see it firsthand" (T6 Interview). She brings green chemistry into other subjects as an elementary teacher, such as social studies and civics. Students learned that they could write to their representatives about the issues they were concerned about. They took pictures of themselves collecting single use plastics, posted social media content around their learning of how it harms the environment, wrote a letter to their representative and got a response. The laws were changed shortly thereafter, and the representative contacted the class to let them know that their efforts mattered in the process. These students keep in touch with T6, coming back years later to ask about plastics, food chemicals, fingernail polish chemicals. They have increased their awareness in elementary school, where the learning has transformed them into people who think about how chemicals can impact them and where they have learned how to be engaged citizens and what the process is to apply their learning for change. These students are also reflecting the concepts that Kezar et al. (2018) found, where the transformational learning of the CoT are taken into other CoP (loosely, as they take this into other classrooms and community spaces that may not formally be CoP), and learning is advanced in those spaces too.

Overall, the teachers who described transformational learning in their students and in themselves also described sometimes being the only one in their school who was practicing green chemistry and the process they engaged to share their learning with other teachers so their classrooms could benefit too. Often there was resistance as other teachers were not comfortable with any concepts of chemistry, reflecting Kezar et al.'s (2018) discussion of how when individuals engage new practices it "might be challenging given their current environment" (p.837). The respondents also described how coworkers came along after seeing the classroom engagement, experiencing the safety of replaced and better functioning chemical closets, or seeing the way that students responded to the green chemistry learning. These coworkers may have needed to experience the "disorienting dilemma" of their old practices versus the effect of green chemistry practices to shift them into participating in this transformational learning process (Kezar et al., 2018).

Higher Ed Faculty Perceptions of CoP

The higher ed faculty (Respondents H1-2) were asked about their collaborations between themselves and K-12 teachers and also to describe the successes, challenges and learning. H1 described the affinity he had with K-12 teachers and having considered becoming a high school chemistry teacher before pursuing higher ed education in chemistry and biochemistry. His interaction with K-12 teachers were initially around PD that his college provided with financial support from a state institution, the Department of Environmental Conservation (DEC), with a particular focus on safety through lab cleanouts and chemical replacement to meet shared goals. H2 has been involved with teachers in supporting high school scientific research programs, after responding to teachers' request for help. He has recently been supporting one teacher who coordinates this program to match her students to college research faculty. She has done this

through she and her students reaching out through web searches, emails, and networking. H2's collaboration reflects Tomaneck's (2017) findings around successful partnerships being in response to the needs of teachers and their classrooms. The students are in a two-year program that prepares them to be ready to do research in college so "they hit the ground running" (H2 interview) with basic knowledge of research, and actual research experience, having fully gone through the process in high school.

H1 stated that initially he was involved in the experience because he was on a tenure track and being involved helped him build his promotion, which reflects Dolan and Tanner's (2017) and Zhang's et al. (2021) findings regarding incentives for collaboration that include recognition of faculty for their service and building this service into the tenure track system. He also stated that he got paid when there was a grant involved. H2 stated that he was initially involved because he did the program when he was a high school student himself, but it got shut down before he could actually do research, "so part of that is me going back and helping students do what I never got to do" (H2 interview).

Both H1 and H2 stated that they remained involved because of the relationships that were built in the partnerships. H1 reflected that the collaboration with teachers and faculty helped him realize that every time "I taught a faculty member or a teacher they would teach like, a thousand students, which is reaching a much broader audience" (H1 interview), which is consistent with Cannon et al.'s (2023) and Nahlik et al.'s (2023) philosophy of training the trainer versus working directly with students to spread the concepts of green chemistry.

H1 also cited the social justice aspect of collaborating to spread the concepts of green chemistry into K-12 classrooms as being very important. He expressed a desire to increase understanding amongst teachers and students of the harmful effects of "industrial byproducts and

the most negative effects of chemistry" because they are the most vulnerable to these effects. He discussed vertical alignment concerns a little differently than the K-12 teachers, suggesting that while it is vital to teach green chemistry at the college level, if it isn't taught in the K-12 classrooms than "scientists are the only ones who know about it… what you really want is for students to have heard about it in high school chemistry and take it to whatever field they go into as something that matters" (H1 interview). Respondent T4, a K-12 teacher with a degree in chemistry, discussed vertical alignment too, expressing a desire to collaborate with higher ed faculty to talk about what high school teachers needed to do to prepare students for first year college chemistry the same way that she and her high school science teacher peers spoke with eighth grade science teachers to collaborate in how to prepare eighth graders for high school chemistry.

H2 worked with the teachers to facilitate student researchers having direct access to research faculty and was finding it to be very challenging, albeit rewarding. H2 saw the value of the vertical alignment of high school students coming into STEM fields in college with two years of the research experience, ready to dive into more complex aspects of these fields. The challenge was to find mentors in the research colleges. A big part of the faculty, teacher, student collaboration is trying to figure out "how we can better connect students to professors… it's tough right? They don't have time, there's no money involved here. But these are really hungry [eager] students, and it's an important part of the pipeline" (H2 interview). He further stated that "if you're trying to get an R1 or R2 professor to engage with a high schooler, they need to see the value" (H2 interview). This tracks with the concerns that Zhang et al. (2021) discuss around incentives such as release time and stipends for faculty, and Moreno's (2017) recommendation regarding better incentives for STEM faculty and adapting systemic processes, and Dolan and

Tanner's (2017) recommendation, that these should also include tenure and promotion. H2 expressed frustration because he saw the potential for transforming the research process through a higher ed/K-12 collaboration but was struggling to find faculty to support this innovative program.

H1 has been involved with Beyond Benign's LTP and the larger CoP, facilitating PD with teachers, facilitating peer-to-peer learning, lab creation, co-authoring lab guides with the LTs to publish as an OER, co-authoring research articles about the collaborative GCCoP in his state, and he continues to stay in contact with many of the LTs post LTP and PD. He shared how the teachers are not only a connection to the students but also to the community in educating people about the concepts of green chemistry. He gave examples of teachers that became advocates to other teachers, bringing them into the GCCoP in any way possible, teachers who used open house at their schools to do green chemistry experiments with the parents in order to "decrease their fear of chemistry, demonstrate the safety of green chemistry, and to show other teachers what the benefits were to bringing parents onboard" (H1 interview). H1 continues to collaborate with Beyond Benign through co-authoring papers about the process of building the GCCoP in his state.

Recommendations

The results of this research suggest that several recommendations from the collaborators themselves. One recommendation is reaching out to the list of Certified Lead Teachers to find out if they are still practicing green chemistry in their classrooms, if they are collaborating in any other spaces, if they have shared their practices with other teachers, if they are members of a state PLC involving green chemistry, and seeking ways to re-engage them through involving them in presentation opportunities, encouraging their participation in the GCTLC as a

community, setting up a reunion to refresh connections and generate ideas for ongoing collaboration in K-12. Another recommendation is to reach out to GCC signers to find out which ones are working with K-12 partners in their regions and interview them regarding their collaborations and how they are unfolding. It would be useful to create a facilitated learning space, such as a virtual meeting, to invite K-12/higher ed partnership groups to share their learning. For the most recent two groups of LTs/CLTs it would honor their collective efforts and generate more peer-to-peer learning and collaboration to put together a mini Summit, even virtually, perhaps with the help of some of those higher ed partners, to discuss next steps in their engagement in the community as "free agents" and to find a clear path for them to keep working with the GCCoP, whether with stipends or not. One suggestion that came up from respondents was to utilize Beyond Benign's Content Manager to facilitate collaboration in adapting higher ed labs/lesson plans for high school use to supplement the vertical alignment process. It will be very important to work closely with K-12 educators to continue making the GCTLC more accessible, user-friendly, and K-12 fluent in every way possible so as not to put teachers off, as Moreno (2017) describes by the way PhD chemists ask questions.

Limitations of the Project

The limitations of this project include the number of higher ed partners and educators (who were not also team members) that were interviewed. It would be useful to include more higher ed partners with experience in K-12 collaboration to discover what is working well, and what challenges must be learned from to find success. Including more K-12 teachers who were past participants of the LTP would help to discover the extent of their ongoing collaboration in the GCCoP since completing the program, and where their engagement and practice points are.

Another limitation of this capstone is the newness of the GCTLC which limits determination of its potential to engage the current community, and if it is currently accomplishing what it is setting out to do as a platform designed to help members of the GCCoP foster deeper engagement and collaboration with one another. As of this writing, it is less than a year old. While it shows promise with the rate that participants are signing onto the platform to utilize it, it certainly has not been able to reveal its potential in connecting K-12 and higher ed educators as possible collaborators thus far.

Implications for Future Projects

The members of each area of the CoP/CoT have described a desire to foster development of the K-12 community however possible. This suggests that there is a need to create more spaces for this discussion to unfold. These spaces should include more higher ed and K-12 partners to identify some potential areas to start. As was discovered with the Beyond Benign team, engaging more collaborators, and a wide variety of them, increases the quality of the results of the collaboration and the innovation of the problem-solving due to the diversity of perspectives involved. The concept of vertical alignment between K-12 and higher ed, particularly with regard to sustainable sciences and access to green chemistry philosophies may be a place to start, as all three groups mentioned the idea of helping students realize their own potential to be agents of change utilizing the philosophy of green chemistry.

Another area that may be explored is how to create engagement through bringing participants of education courses immediately into the arena of service to create a sense of belonging and relevance to the wider CoP, for example asking online course participants to share the work they create in their courses at future webinars and on the GCTLC, or asking GCC signers to share their learning at the Green Chemistry Connections webinar or at conferences.

Perhaps exploring internally a way to be systematic about this process, so that there is a defined path whereby learners can immediately become contributors, fostering a sense of belonging, a sense of the value of the learning process, a sense of involvement and the value of contribution and how it strengthens the CoP, creating agency and investment in the process, and leading to more opportunities for transformation. Tracking this experience through surveys and focus groups may help generate a better understanding of how to increase engagement of participants to transform them into agents of change, and also reveal how to accompany participants more effectively into the field of service.

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Appendix A

Capstone Interview Questions

Beyond Benign K-12 Strategic Plan

Beyond Benign Team Members

1. Tell me about your Beyond Benign role and your assumptions about it as you signed on as a team member.
    a. How has this evolved after being here for a length of time?
2. What are your thoughts and beliefs about being part of a Green Chemistry CoP?
    a. Has this understanding evolved since you became part of the team?
    b. How has the learning you are experiencing been part of shifting your understanding of the community and how to serve and grow with it?
3. How do you see your role as connected to the other roles/programs in Beyond Benign?
4. What do you see as common goals of your program and…K-12/Higher Ed/GCTLC?
    a. How do you see your program's work as supporting the work of the other programs and vice versa?
5. What is your experience around the K-12 program during your time at Beyond Benign?
6. What is the value that you see in the K-12 program to the mission of Beyond Benign?
7. As you reflect on Beyond Benign and its role in the future with CoPs and other partnerships, where do you see Beyond Benign having the most impact? How do you see this role unfolding?
8. Is there anything else you think would be useful for me to know about Beyond Benign and this CoP that would increase my understanding?

Teachers

1. How do you see yourself as part of the Green Chemistry Community of Practice (GCCoP)?
    a. How have you been able to contribute to the collective process of the GCCoP?
    b. What is your understanding of the common goals of the CoP?
    c. Can you share some examples of some of the tools, materials, or language that has evolved or that you have been a part of developing within this CoP?
2. How has your practice of green chemistry in the classroom been impacted?
3. Do you see yourself as an ongoing collaborator in this CoP?
    a. If yes, do you feel supported as a collaborator? Please share some examples of this support.
    b. If not, please share why you don't feel supported? Please share what some of the challenges are from your perspective.
4. Describe any collaboration you have had that includes college/university faculty?
    a. How did you become involved in this collaboration?
    b. Did it involve professional development (PD) training?
    c. Please describe any collaboration beyond the PD, and if it is ongoing?
5. Describe your experience with Beyond Benign during your participation in this CoP.
    a. Reflect about the successes or challenges of the process.
6. Is there anything else that you think would be important to know about this CoP?

Higher Ed Faculty

1. How did your K-12 partnerships begin and what did they look like?
2. What did you learn from the challenges/successes/collaboration?
    a. What are the things you might do differently?
    b. What things would you replicate each time?
3. How do you see your relationship with K-12 education?
4. What are your thoughts about the connection between K-12 and higher education?
5. How do you see the relationship between K-12 green chemistry education and higher ed green chemistry teaching/practices?
6. How might Beyond Benign support the building of future collaborations between K-12 and Higher Education?

NOTES:

Team Member questions developed from Mezirow's Transformative Learning Theory framework: *disruptive dilemma/experience*; *critical reflection* as a result of collaboration/mentoring; developing a *plan of action* that reflects new learning

Partner questions developed from Lave and Wenger's and Wenger-Trayner and Wenger-Trayner's CoP framework: *joint enterprise or domain with agreed upon and shared interest, commitment, and competence* in a collective process, *mutual engagement or community* where common goals are developed and worked toward in activities, discussions and information for the purpose of learning; and *shared repertoire or practice* where there is shared language, tools, ideas, frameworks, resources and understanding.