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The Influence of Faculty Peer Network Communication in the Diffusion of a Centralized CURE

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THE INFLUENCE OF FACULTY PEER NETWORK COMMUNICATION IN THE DIFFUSION OF A CENTRALIZED CURE

by

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(Under the Direction of Sue Ellen DeChenne-Peters)

ABSTRACT

Course-based undergraduate research experiences (CUREs) provide students the benefits of undergraduate research participation by incorporating authentic scientific research into laboratory courses. CUREs are a relatively young pedagogy and are therefore innovative. Roger's (2003) diffusion of innovations (DOI) framework posits that the diffusion of innovations, such as CUREs, is a highly social process. Most existing CURE research has focused on the impacts to students and the critical elements of CURE design. Investigation into instructor peer network communication is largely absent from the existing CURE literature. This study investigates the structure and function of a CURE community – the Malate Dehydrogenase CURE Community (MCC) – throughout the innovation adoption process using qualitative analysis of in-depth interviews with thirteen MCC members. This study established that the CURE community functions as both a community of practice for fundamental malate dehydrogenase research and as a faculty learning community for teaching CUREs. The MCC also serves vital functions throughout each stage of the adoption process. While CURE adoption is still in the early stages of diffusion, the MCC has reached critical mass and is therefore a viable model for the design of CURE communities that wish to facilitate sustained CURE adoption.

INDEX WORDS: Course-based undergraduate research experiences, Biology education research

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DEDICATION

The past two years have taught me that, much like raising a child, writing a thesis takes a village. Therefore, I'd like to dedicate this work to my family, including those individuals I consider an extension of it. To my mother, Carol Daniels, for always pushing me to pursue an education and celebrating my academic accomplishments. To my partner, Mike Smolkovich, for his unwavering support and belief in my abilities. To my best friend Jessica Howard, for being my long-distance cheerleader. To my dear friend Yvette Wheeler, may she rest in peace, for always helping me navigate the challenges of post-military life. To my mentor, Dr. Sue Ellen DeChenne-Peters, for helping me discover my passion for biology education research, for pushing me to surpass my comfort zone, for seeing my potential even when I could not, and for her unending patience. And finally, to all the incredible friends, teachers, mentors, and students I've encountered along the way. My life has truly been enriched by my time at Armstrong State University and Georgia Southern University.

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INTRODUCTION

Background Context

The call to reform science education within the United States has been sounding for decades, but recently it rings with increasing urgency. For over 70 years, the United States (U.S.) was a powerful leader in science, technology, engineering, and mathematics (STEM) innovation (National Science Board, 2020b; President's Council of Advisors on Science and Technology, 2012). This dominant status was a source of pride reflected in the nation's culture and relied heavily on a relatively small but highly capable STEM workforce (National Science Board, 2018). Today, science and technology have permeated nearly every aspect of life, both in the U.S. and across the globe. Globalization means technological and social developments occur at breakneck speed, and the U.S. finds itself falling behind as a competitor in science. STEM enterprise has increased both in the U.S. and abroad, but the growth of STEM capabilities in other nations "has outpaced that of the United States along several dimensions" (National Science Board, 2020a). As the STEM activities of other nations increase, the relative amount of scientific discovery represented by the U.S. decreases – even as the country's research and development investment and expenditure continually increase (National Science Board, 2020b). While the ubiquity of scientific innovation has drastically improved most sectors, such as healthcare, agriculture, and national security, it also necessitates a change in American culture: society can no longer rely on a small, largely homogenous STEM workforce to solve increasingly complex issues.

Today, there are more than 36 million STEM workers, which represent 23% of the total U.S. workforce. STEM workers earn a higher median annual salary than non-STEM workers, the STEM unemployment rate is half that of non-STEM sectors (2% versus 4%, respectively, in 2019), and STEM jobs were less susceptible to disruptions such as the COVID-19 pandemic (National Science Board, 2022). STEM and STEM-adjacent occupations have expanded faster and have more aggressive growth projection than non-STEM jobs (an expected 13% increase for STEM vs 7% for non-STEM by 2026) (National Science Board, 2020b, 2022). The burgeoning growth, relative security, increased visibility, and wage potential of STEM jobs make science an alluring sector: in 2019, 43% of ACT-tested high school graduates showed an interest in pursuing STEM as a major and/or career (ACT, 2019). Yet less than 50% of those students who enter college intending to major in a STEM subject graduate with a STEM degree (Seymour et al., 2019). These statistics have led to intense examination of science education in the U.S., and reform efforts have revealed that the STEM deficit is not only one of numbers, but also of representation.

A diverse workforce is a powerful workforce. Compared to heterogenous groups, homogeny reduces problem-solving efficacy (Hong & Page, 2004), accuracy (West & Dellana, 2009) and innovation (Hofstra et al., 2020; Rogers, 2003). The U.S. is a heterogenous "melting pot" of races, ethnicities, genders, and sexualities, and therefore should present a diverse STEM workforce – and yet the demographic composition of STEM workers does not reflect that of the nation's populace (National Science Board, 2022). Women represent 50.1% of the country's population and 47.1% of employed Americans, but only 34% of the STEM workforce (National Center for Science and Engineering Statistics; National Science Foundation, 2021; National Science Board, 2022). People with disabilities make up 26% of the adult population (Okoro et al., 2018), but only 10% of employed STEM workers (National Center for Science and Engineering Statistics; National Science Foundation, 2021). At least 10% of the U.S. population identifies as a member of the lesbian/gay/bisexual/trans/queer/intersex/asexual (LGBTQIA+) community (GLAAD & Harris Poll, 2017), but are believed to be significantly underrepresented in STEM, although exact data on the prevalence of LGBTQIA+ identity in STEM is not collected as rigorously as that of other demographics (Sansone & Carpenter, 2020). Additionally, systemic marginalization of certain groups has resulted in those persons being excluded from science due to ethnicity or race (PEERs) (Asai, 2020). Of the U.S. population between 18 and 64 years old, 59% are White – yet White persons represent more than 66% of the full-time STEM professional workforce (National Center for Science and Engineering Statistics; National Science Foundation, 2021). Black, Hispanic, and Indigenous Peoples represent 30% of U.S. labor, but only 23% of the STEM workforce (National Science Board, 2022). Furthermore, it is projected that non-White races and ethnicities will represent 56% of the U.S. population by 2060 (National Center for Science and Engineering Statistics; National Science Foundation, 2021). While efforts at reducing the disparity in representation have made progress, those efforts lag behind the shift in the country's demographic trends (National Science Board, 2020b)(National Science Board, 2020b). It is increasingly obvious that to remain a leader in STEM, the U.S. must improve both accessibility and inclusion in STEM for all citizens.

These issues have facilitated an intense examination of STEM in America, particularly the pathways to a STEM career. The metaphor of a "pipeline" is often used to describe the path to a career in STEM, with the "pipe" running from childhood education to a desirable STEM job via a STEM college degree between the two. Problems with this STEM education pipeline were already being investigated by the 1990s (Seymour et al., 2019). A 2012 report to the president estimated that to maintain its position as a global leader in science and technology through 2022, the U.S. needed to produce an additional one million STEM professionals, or a 34% increase beyond the then-current rate of STEM graduates (President's Council of Advisors on Science and Technology, 2012). The same report identified high attrition rates in college STEM programs as a major contributing factor to the dearth of STEM workers. Of students entering college intending to pursue a STEM major, less than 40% persisted to graduation with a STEM degree (President's Council of Advisors on Science and Technology, 2012). Retaining a mere 10% of those students who exited the STEM degree pipeline would sufficiently supply the country's STEM labor needs (President's Council of Advisors on Science and Technology, 2012). More recent studies estimate that approximately 48% of students who enter college intending to major in a STEM degree end up leaving their STEM major (Seymour et al., 2019). Of those students who exit their STEM degree, 28% do so by switching to a non-STEM degree and 20% leave school altogether with no degree at all (Chen & Soldner, 2013; Seymour et al., 2019). High attrition rates are an issue across the science disciplines, but biology has one of the highest rates of switching to non-STEM degrees (20%), second only to mathematics (24%) (Seymour et al., 2019). When examining the pipeline metaphor in light of these sobering attrition rates, it becomes obvious that the STEM pipeline is leaking at the postsecondary education level.

The loss of talent at the college level exhibits distinctive patterns that promote disparity and exclusion. Women and PEERs enter college with an interest in pursuing a STEM degree at a rate similar to or greater than their White and/or male peers yet leave at significantly higher rates (Gentile et al., 2017). Seymour et al. (2019) conducted a five-year study of 1,437,806 transcript records to investigate attrition and persistence rates in STEM majors. They found that women students, students who experience high academic stress (such as a D/W/F/I grade) in their first year, and non-White/non-Asian students all switch out of STEM degrees at a higher rate than their peers. Regression analysis revealed that by themselves, race, ethnicity, or belonging to another marginalized population did not predict switching. Academic indicators of preparedness (such as SAT/ACT math scores) were better predictors of switching/persistence. Riegle-Crumb, King, and Irizarry (2019) similarly found that Black and Hispanic students are significantly more likely than their White peers to switch from STEM to non-STEM degrees, and this phenomenon is not present in non-STEM fields (Riegle-Crumb et al., 2019). Other studies revealed that LGBTQIA+ students are less likely to persist in STEM than their cisgender and/or heterosexual peers, despite high individual academic performance (Hughes, 2018; Maloy et al., 2022). Attrition and persistence rates in STEM degrees are complex, and problems within science education can affect all students. These results, however, add to the mounting evidence that some qualities of STEM education are disproportionately exclusionary.

Seymour et al. (2019) found the same complaints about STEM education were shared by both students who stayed in STEM and those who left. Among the top complaints: STEM instructor pedagogy (72% of persisters, 96% of switchers), STEM curricular design (56% of persisters, 85% of switchers), difficulty getting timely help (31% of persisters, 80% of switchers), loss of confidence (44% of persisters, 79% of switchers), and competitive class climate (42% of persisters, 81% of switchers). For women students, poor teaching, loss of confidence, and the competitive climate of STEM were major issues. It is of note that nearly half of women STEM students and nearly half of male STEM students both cited poor teaching practices as a major challenge. Women were disproportionately affected by loss of confidence, as reported by 67% of women students versus 51% of male students. Perhaps unsurprisingly, loss of confidence was a greater issue for women who switched out of STEM (84%) than those who persisted (49%), a trend also seen in male students (71% switchers vs 37% persisters). The competitive climate of STEM was an issue for 56% of women students, versus 46% of male students, and appears to have greater impact on those who leave STEM (85% of women, 74% of men) than those who stay (52% of women, 30% of men). Both women and men students reported problems related to STEM curricular design, such as high volumes of coursework coupled with the fast pace of introductory courses, versus teaching approaches used in non-STEM courses (Seymour et al., 2019, Chapter 1). Curricular design was a major issue for students who left their STEM degree (95% of men, 82% of women) but also impacted more than half of those students who stayed (55% of men, 59% of women). These results indicate that issues in the delivery of STEM education impact all students but are an especially strong driving force for those who leave.

In the same study, Seymour et al. (2019) found that PEER students in STEM were disproportionately affected by under-preparation, difficulty transitioning to college, the competitive climate in STEM, and loss of confidence. Preparedness for college is commonly measured by students' performance in mathematics in standardized tests such as the SAT or ACT, as there is a demonstrated relationship between academic background (enrollment in AP courses, a high GPA in high school, ACT/SAT scores) and persistence in STEM. Yet even students who performed well in STEM courses in high school or had high scores on standardized tests often perceive that they are under-prepared for college-level STEM courses once they have experienced these courses. Under-preparation is a complex phenomenon with many contributing factors, however the most common causes cited by students who perceived themselves to be under-prepared were poor quality teaching in high school, courses that were not challenging, or those that relied on memorization, as opposed to their college courses which demanded higher-level engagement with concepts and their applications (Seymour et al., 2019, Chapter 5). Under-preparation affected 35% of all PEER students versus 13% of all White students, and this issue was seen both in switchers (73% of PEER switchers, 60% of White switchers) and students who persisted to graduation (41% of PEER persisters, 31% of White persisters). Difficulties transitioning to college were reported by 73% of PEER students compared to just 31% of White students. More PEER students who persisted to graduation struggled in this area (78%) than their White classmates (45%), but for switchers, high numbers of both groups struggled with the transition (96% of PEER switchers and 86% of White switchers). 62% of PEER students were negatively impacted by the competitive climate in STEM, compared to 49% of White students. The competitiveness was also a major complaint for switchers of both groups: 88% of PEER switchers and 79% of White switchers, but disproportionately affected PEER students who stayed in the degree compared to their White classmates (60% of PEER persisters, 32% of White persisters). Loss of confidence was also a greater issue for all PEER students (69%) than their White peers (59%) but was significant for switchers from both groups (92% of PEER switchers, 74% of White switchers) and disproportionately affected PEER persisters (59% PEER persisters versus 35% White persisters) (Seymour et al., 2019). Loss of confidence can stem from several factors but is often related to a lack of interpersonal relationships with other STEM majors, low self-efficacy, absence of personal scientific identity, and loss of interest in the subject matter (Rainey et al., 2018). It is of note that while the most common complaints of both women and PEER students were also seen in White students and had greatest impact on switchers from all groups, these issues disproportionately affected women and PEER persisters compared to White persisters. These trends make women and PEER students feel "pushed out" of STEM and contribute to the greater attrition rate seen in these groups but are also stressors for those who stay to complete their degree (Seymour et al., 2019).

Furthermore, no student exists in a vacuum. Race, ethnicity, and gender are only three parts of a student's identity, which is also shaped by factors such as socioeconomic status and lived experiences. Intersectionality refers to the intersection of an individual's internal sense of self-identity with their external sense of social identity and experiences (Ireland et al., 2018). Individuals belonging to multiple marginalized groups experience unique issues and challenges from the effects of multiple marginalization. Loss of confidence is a major issue for both women and PEER STEM students, and is related to sense of belonging, so it is unsurprising that both these groups experience significantly decreased sense of belonging in STEM – but PEER women felt the least sense of belonging (Rainey et al., 2018). Undergraduate students often internalize messages from multiple sources that success in a STEM degree requires inherent natural ability and/or access to extensive, high-quality preparation programs before college, a resource not equitably available to all students (Malcom & Feder, 2016). This internalization of exclusionary messaging combined with low sense of belonging can result in low self-efficacy and self-confidence, which are both correlated with STEM attrition for students who belong to groups historically underrepresented in STEM – particularly women, non-White races, ethnicities, LGBTQIA+, and students with disabilities (Gentile et al., 2017). LGBTQIA+ students also report a low sense of belonging and are 7% more likely than their heterosexual peers to leave STEM degrees, and this effect is not mediated by high academic performance or interest in STEM (Hughes, 2018). Students with disabilities enroll in STEM degrees at rates similar to those without disabilities (28%) but are 4% less likely to be enrolled full time at the same institution one year later (National Science Foundation & National Center for Education Statistics, 2019). It is evident that however unintended, qualities of undergraduate STEM education are contributing not only to the high attrition rates of STEM students, but also the disparity between which students leave and which students stay.

To remain relevant, STEM education must adapt not only to the changing population demographics of the twenty-first century learners, but also the real-world problems they face both during and after graduation. Forty-two percent of students attending college full-time also have jobs, as do 80% of part-time students, and 33% of those working learners are at least 30 years old (Business Higher Education Forum, 2019). The prevalence of working students may be a contributing factor to the increased time to degree completion among STEM students. Only 22% of STEM students completed their degree in 4 years; most students now finish their degree between 5 and 6 years after program entry (Malcom & Feder, 2016). Students who work while attending college often do so out of necessity; financial problems interfering with the ability to complete a STEM degree negatively affect both STEM switchers (70% of switchers) and persisters (48% of persisters) (Seymour et al., 2019, Chapter 11).

For those students who persist in STEM, attainment of a degree does not automatically translate into career or even job placement success. Jelks and Crain (2020) found that nearly one-third of STEM students reported difficulties finding jobs within their desired field and higher likelihood of perceiving barriers to employment such as overqualification, being geographically constrained, and lacking social connections. Students who were unable to quickly find a STEM job relevant to their professional interests and goals after graduation were 17% more likely to have left the STEM workforce by 30 years old (Jelks & Crain, 2020). The inability of competent STEM students and workers to find and obtain gainful employment in STEM jobs is known as diversion; these STEM students are diverted from the STEM pipeline (Seymour et al., 2019).

The leak in the STEM pipeline does not originate in postsecondary STEM education. Under-preparation in K12 for STEM college education is commonly reported by PEER students (Seymour et al., 2019). Nor does the leak end after students have attained a STEM degree. Successful STEM workers must be both scientifically and technically competent and therefore the goal of STEM education is to produce such workers and empower them to find suitable employment after graduation (President's Council of Advisors on Science and Technology, 2012; Seymour et al., 2019).

Evidence-based Instructional Practices

In the quest to find solutions to the problems plaguing STEM education, discipline-based education research (DBER) has flourished. DBER experts act as change-agents within their respective STEM disciplines, investigating and promoting the use of evidence-based instructional practices (EBIPs) in STEM teaching reform (National Research Council, 2012)

The use of EBIPs in STEM education benefits all students, but is crucial in addressing the multiple disparities present in the field, including those of race/ethnicity and gender. Research overwhelmingly shows that students benefit more from active-learning strategies over the "traditional" passive information delivery system of lecture-based learning (Deslauriers et al., 2019; Freeman et al., 2014; Styers et al., 2018). As a result, change agents such as the National Science Foundation have laid out strategic plans for the implementation of inquiry-based, applied learning in the reform of STEM education (AAAS, 2011; National Science Board, 2020b; National Science Foundation, 2020).

Despite the sustained collaborative efforts to facilitate the widespread implementation of EBIPs into STEM undergraduate education, lecture-based content delivery continues to be the predominant form of instruction in colleges around the country. One observational study of 71 foundational STEM courses found only 26% of classrooms utilized evidence-based strategies (Seymour et al., 2019). A much larger study observed 2008 STEM classes (encompassing 709 different courses taught by 548 individual instructors at 24 institutions) and found that 55% of observations consisted of didactic-style instruction in which 80% or more of the students' class time was spent listening to the instructor lecture; only 18% of the observed classes were comprised primarily of student-centric teaching strategies (Stains et al., 2018) The remaining observations included a mix of didactic and interactive material, such as clicker questions and small group activities (Stains et al., 2018). Ninety-nine percent of undergraduate students who switch out of STEM degrees described their courses as non-interactive, lecture-based instruction, and 57% of students who persisted in STEM to graduation reported that the majority of their STEM course experience was lecture-style teaching (Seymour et al., 2019). Only 33% of those who persisted in STEM to graduation and 26% of those who left STEM degrees reported taking classes that utilized interactive instructional strategies. Despite the growing body of literature demonstrating the benefits of student-centric teaching practices, most undergraduate STEM courses are still being taught using passive information-transfer techniques.

Undergraduate Research Experience

While interest in EBIPs and active-learning strategies is increasing, the idea that STEM students learn science best by doing science is not a new one. Research experience is a pivotal component of many STEM careers and may serve as inoculation against factors contributing to attrition in STEM education and the exodus from the STEM workforce (Estrada et al., 2018; Hernandez et al., 2018; Jelks & Crain, 2020). Even for those STEM professionals not actively pursuing scientific research as part of their professional capacity, past participation in research activities can contribute to professional success such as job placement and career satisfaction; one study found that holders of a STEM bachelor’s degree who participated in faculty research as undergraduate students were 14% more likely to express intent to persist in the field of STEM (Jelks & Crain, 2020). Anecdotally, participation in research as a young scientist is often described as a pivotal event in STEM professionals’ career trajectory (Gentile et al., 2017). Earlier exposure to and participation in scientific research shapes individuals’ perspectives of STEM and acts as a gateway through which students are semi-formally initiated into the scientific community while they engage more deeply with science (American Association for the Advancement of Science, 2011; Gentile et al., 2017; Krim et al., 2019). Yet in a 2018 poll, only 22% of STEM majors strongly agreed that they had a STEM mentor (National Academy of Sciences, 2019). Therefore, it is beneficial that individuals be exposed to and be provided the opportunity to participate in STEM research as early as possible (Gentile et al., 2017). One way of providing these experiences early is by providing research opportunities for undergraduate students, or undergraduate research experiences (URE).

The benefits of URE participation for students are numerous and well-documented (Gentile et al., 2017; Hernandez et al., 2018; Joshi et al., 2019; Krim et al., 2019; Linn et al., 2015). Research participation increases students' self-confidence, self-efficacy in STEM, sense of science identity and knowledge of potential career paths, sense of belonging to the scientific community, and ultimately, persistence in STEM (Estrada et al., 2016, 2018; Gentile et al., 2017; Joshi et al., 2019) . These benefits of participation in research as an undergraduate are so profound, they have been acknowledged in education research literature and policy for over 30 years (Gentile et al., 2017).

Traditionally, STEM disciplines have relied on a dyadic apprenticeship-style mentoring model to provide undergraduate students research experience opportunities. In this model, a student works directly or in a small group with a faculty member on that faculty member's ongoing research. Undergraduate research is a double-edged sword: despite the clearly demonstrated benefits to STEM students, the apprenticeship-style model of undergraduate research experiences contributes to disparities in the field of STEM (Wei & Woodin, 2011). As STEM fields have evolved over time, so too have research opportunities, as well as academic context. The dyadic mentorship model places obligations on both the faculty member and the student researcher. Faculty members have numerous professional obligations outside of teaching, and mentoring undergraduate research requires a significant investment of time, funding, and cognitive energy; thus, limiting the amount of undergraduate researchers each faculty member can effectively mentor (Gentile et al., 2017). These factors make opportunities for undergraduate students to participate in research limited, and therefore introduce a sense of competitiveness for these positions.

Undergraduate students face similar barriers to URE participation with competing obligations on their time and cognitive energy as they navigate college culture/adult life and coursework, but some face higher barriers than others. Students that belong to groups historically excluded from STEM must find strategies to overcome challenges such as a lack of representation, conscious and unconscious bias, cultural differences, and lack of adequate support systems within their institution. First-generation college students may not be aware of the need for research experience to present as a competitive candidate applying for STEM graduate programs or employment in the STEM field or may obtain the knowledge too late in their degree path to participate in a URE. The “nontraditional” college student has become more commonplace; students with caregiver obligations or who are employed outside of school may not be able to dedicate the time required for research in addition to that required for their normal studies. Socioeconomically disadvantaged students may not be able to afford to travel to research that occurs off campus or provide their own equipment, such as portable electronics. Neurodivergent students – those with conditions such as autism, attention deficit hyperactivity disorder, dyslexia, dyspraxia, dyscalculia, Tourette syndrome, and learning disabilities (Doyle, 2020) – may struggle with the social aspects involved in research, such as seeking out a faculty member or assimilating to lab culture. Students with disabilities may have limited resources such as time or energy to dedicate to research, as well as accessibility concerns within the lab. This means that UREs are a potential source of exclusion and disparity within STEM, including biology (Aikens et al., 2017; Grineski et al., n.d.).

In response to these issues, government agencies recommended close examination of barriers to undergraduate participation in research, and the role of policies or practices that facilitated these barriers (Gentile et al., 2017). Among these recommendations: traditional, didactic-centric laboratory courses be replaced with inquiry-driven curricula (President’s Council of Advisors on Science and Technology, 2012).

Course-based Undergraduate Research Experiences

Course-based undergraduate research experiences (CUREs) are an alternative option to faculty-mentored research experiences. CUREs bring scientific research into the classroom environment, where all students in the class experience the novelty and inquiry of scientific research in courses that contribute towards their degree. CUREs have been demonstrated to produce similar benefits as faculty-mentored research, while also reducing the performance disparities in student outcomes that exist between "traditional" students and students belonging to populations that have been historically underrepresented within STEM (PEERs, LGBTQIA+, neurodivergent, people with disabilities, etc.). In addition to improving conceptual understanding, CURE participation increases conceptual knowledge, confidence, self-efficacy, scientific identity, as well as providing collaboration, career guidance, and networking opportunities (Bangera & Brownell, 2014; Brownell et al., 2015; Cooper et al., 2019; Dolan, 2016; Gin et al., 2018; Ing et al., 2020; Knope & Munstermann, 2020; Peteroy-Kelly et al., 2017; Rodenbusch et al., 2016). The multitude of benefits from participating in a CURE converge to 1) lower barriers to entry of undergraduate students to participation in scientific research, thus increasing accessibility to and diversity within STEM education, 2) bolster students' confidence and a sense of belonging to the scientific community, increasing persistence and perseverance, raising retention, and lowering attrition in STEM degrees. Ultimately, CUREs contribute to the mission of diversifying and expanding the STEM workforce, while producing a higher quality of STEM graduate.

CUREs are inherently innovative. Indeed, many instructors turn to CURE adoption as a solution to a perceived problem in their traditional curriculum. Some CUREs may be "home-grown" by a faculty member who wishes to introduce their research into courses they're teaching. Other CUREs are backwards engineered by instructors or reform agents to achieve desired student learning outcomes (SLOs) and then disseminated to other instructors. Regardless of its origin, a CURE can then be implemented by other instructors not involved in its design.

The definition and term CURE is a relatively recent addition to the STEM education research. As such, the conversation about what represents a CURE and what components are most crucial for a pedagogy to qualify as a CURE are ongoing. Yet the idea of implementing a CURE as a best-teaching practice has spread throughout the STEM community. A growing area of research interest is why certain EBIPs fail to “take off” to become widely used despite their demonstrated value for student outcomes and pressure from government and academia for their implementation (Henderson & Dancy, 2007; Stains et al., 2018). Evidence and experience show that most educational reform efforts fail to create lasting change in the instruction practices of individual educators (Andrews & Lemons, 2015; Borrego & Henderson, 2014; Henderson & Dancy, 2007). Much of STEM education reform effort focused on the development of EBIPs and then making the materials to implement the EBIP available to other instructors – a strategy that has seen limited success and resulted in many new curricula that seem to “re-invent the wheel” by failing to build on previous work (Borrego & Henderson, 2014; Henderson & Dancy, 2007). Because it is both still in the relatively early stages of diffusion and has had relative success in diffusing, a flurry of research has occurred surrounding CURE diffusion (Bell et al., 2017; Genné-Bacon et al., 2020; Govindan et al., 2020; Shortlidge et al., 2017). Most of this research, however, has focused on student outcomes and the benefits of participation in a CURE (Cooper et al., 2019; Esparza et al., 2020; Gin et al., 2018; Knope & Munstermann, 2020; Peteroy-Kelly et al., 2017). There is a relative lack of faculty-centric CURE research compared to that of students. Efforts to promote the diffusion of CUREs as a teaching best-practice have focused primarily on identifying where/how instructors learned about CUREs, and what barriers to implementation were experienced by those instructors who adopted a CURE (Brownell & Tanner, 2012; Govindan et al., 2020). There has been a general lack of study into the role peer-instructor communication plays in the context of CURE diffusion and adoption.

Social sciences and marketing research have long acknowledged the role of the individual’s communication networks in change, as does the relatively young field of discipline-based education research (Borrego & Henderson, 2014; Burt, 2004; Gess-Newsome et al., 2003; Lund & Stains, 2015; Neal et al., 2011; Rogers, 2003). Likely in recognition of this, the guidelines put forth by the Vision and Change initiative in 2011 promoted the formation of social bodies (societies, organizations, and "activities") to form a community of "scholar-educators" which would provide faculty professional development opportunities and foster collaboration (American Association for the Advancement of Science, 2011). There exists within the field of educational reform a growing body of research regarding the role of individuals, communication channels, and social networks in the diffusion of innovative pedagogies and EBIPs- but there remains a large deficit of this type of research within STEM educational research, especially regarding the diffusion of CUREs. While the importance of faculty communication is acknowledged as critical to the diffusion of EBIPs- even within CURE-centric publications- this area of research is largely absent.

Framework: Rogers' Diffusion of Innovations

As a relatively young pedagogy, Rogers' *Diffusion of Innovations* (2003) provides a theoretical framework explaining how new ideas are spread and achieve (or fail to achieve) widespread adoption. Since its inception in 1962, the framework (including its revised editions) has been deployed across multiple disciplines, particularly marketing, social sciences, and educational reform, to test, understand, and facilitate the diffusion of ideas.

Rogers frames diffusion as a form of social change. The process consists of 4 main components: the innovation itself, communication channels, time, and the social system (Rogers, 2003). An innovation may be a new type of technology (devices, hardware, or software) or a new idea, such as a novel pedagogy. Once an individual is made aware of the existence of an innovation, the newness of the innovation generates a high degree of uncertainty in the individual- particularly about the innovation's cost, relative advantages, shortcomings, and its applications within the context of the individual's circumstances (Rogers, 2003). To reduce the degree of uncertainty, the individual enters a period of information gathering, and while attaining knowledge about the innovation, forms an attitude towards it (Rogers, 2003). The end objective of this innovation-decision process is to evaluate the innovation and determine whether to adopt or reject it (Rogers, 2003).

The innovation-decision process consists of five stages, as illustrated in Figure 1: knowledge, persuasion, decision, implementation, and confirmation. This process is dynamic and dependent on inherent qualities of both the innovation and the potential adopter, with communication networks as a driving force propelling the potential adopter through each stage. The individual's background and circumstances as they enter the innovation-decision process provide the context in which the process takes place (Rogers, 2003). The knowledge stage begins when the potential adopter becomes aware of the existence of the innovation. This may be initiated passively (such as when a coworker mentions a new pedagogy during a conversation over lunch) or actively (usually when an individual seeks out potential solutions for a problem) (Rogers, 2003). If there is not enough information about the innovation, or if the individual deems it irrelevant to their situation, it will be rejected (Rogers, 2003).

Once the potential adopter acquires enough information, they will move into the persuasion stage. The persuasion stage is characterized by the formation of an attitude toward the innovation; where the knowledge stage is largely a cognitive process, the persuasion stage is affective and involves favorable or unfavorable emotions towards the innovation (Rogers, 2003). In this stage, interpersonal communication networks have the greatest influence as individuals are actively seeking subjective information about the innovation, evaluating the credibility of that information, and forming hypotheses about how the innovation will perform in their situation (Rogers, 2003). This attitude formation funnels the potential adopter towards a critical point: the decision to adopt or reject the innovation (Rogers, 2003).

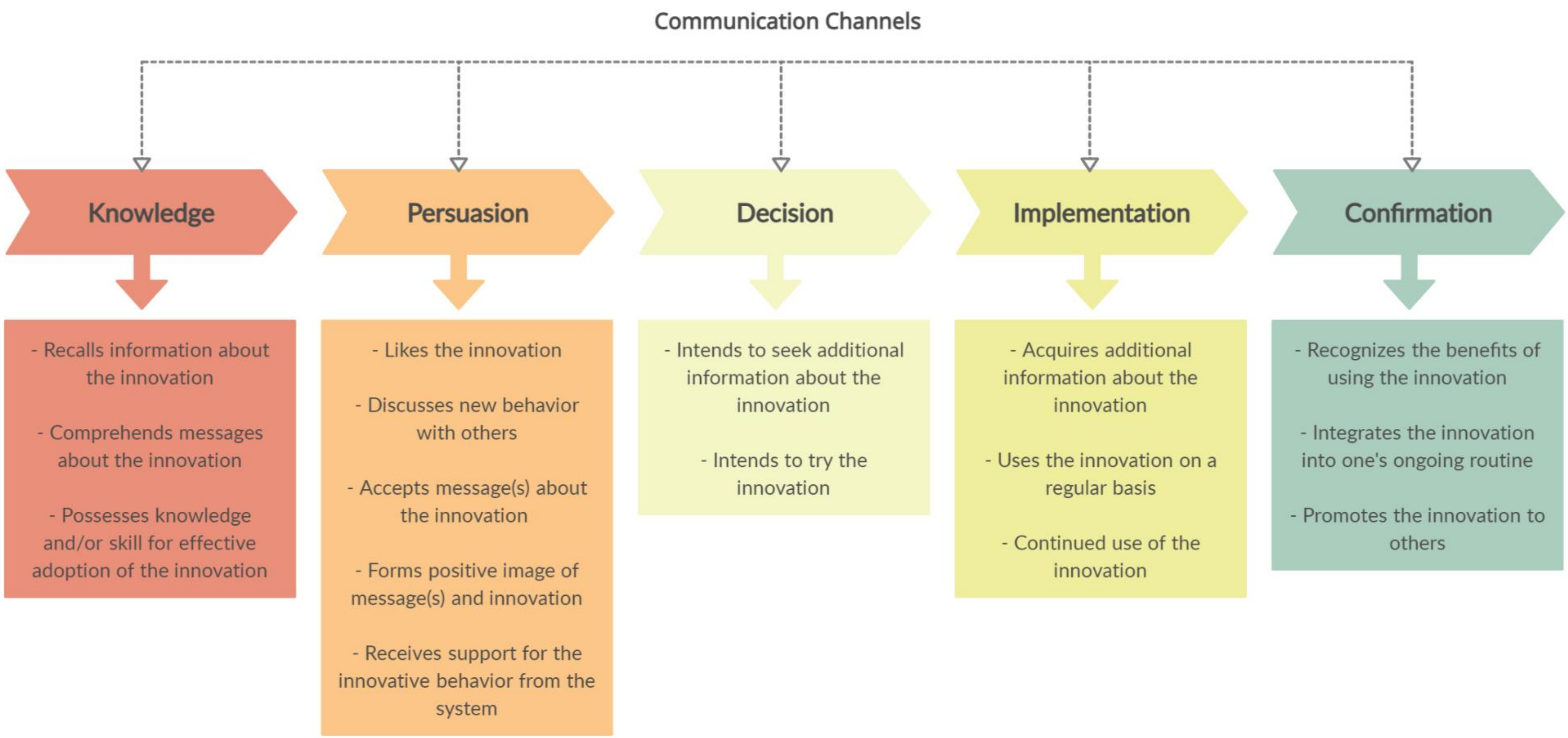

Figure 1: The Innovation Decision Process. Adapted from Rogers (2003), p.170 & p.199. Copyright Free Press, 2003.

In the decision stage the individual engages in activities to further reduce uncertainty about how the innovation will perform in their unique context, such as using the innovation for a trial period or observing first-hand the use of the innovation by persons within their social network (Rogers, 2003). If the decision is made to adopt the innovation, the individual typically enters the implementation stage very shortly after; if the innovation is rejected, the individual will seek confirmation that they have made the best choice (Rogers, 2003).

During implementation, the innovation-decision stops being a hypothetical scenario and the innovation is evaluated through personal trial (Rogers, 2003). The length of this stage can vary widely. Since some degree of uncertainty still remains about the innovation, particularly its consequences, the adopter continues to gather knowledge and reduces uncertainty through experience and observation until they enter the confirmation stage (Rogers, 2003).

In the confirmation stage, the individual seeks reinforcement about the previously made decision. If exposed to messages that conflict with their decision to adopt or reject, they will engage in activities to reduce internal dissonance (Rogers, 2003). Some individuals may reverse their previous decision, but many engage in selective exposure and confirmation bias to avoid having to "change course" (Rogers, 2003).

Underlying each stage of the innovation-decision process are communication channels, which are critical throughout each. The entire diffusion process is a special type of communication in which the messages are about a new idea (Rogers, 2003). Potential adopters are essentially observing and imitating peers within their network who have already adopted (or rejected) the innovation. Diffusion research shows that rather than evaluating an innovation based on scientific studies of its consequences, most individuals rely heavily on subjective evaluations provided by peers (Rogers, 2003).

STEM education research has previously applied Rogers' framework to the diffusion of EBIPs and innovative pedagogies (Borrego & Henderson, 2014; Foote et al., 2014; Friedrichsen et al., 2017; Henderson et al., 2011; Lund & Stains, 2015). Henderson et al. (2011) examined the change strategies utilized by change agents in undergraduate STEM education reform (STEM education researchers, faculty development researchers, and higher education researchers) and found that most change efforts have focused on top-down policymaking and the development and dissemination of new curricula, with relatively little success (Henderson et al., 2011). In a similar vein, Borrego & Henderson (2014) characterized eight change strategies, including Rogers' framework, which the authors advocated be used as a "scattering" and "training" strategy focused on development and implementation (Borrego & Henderson, 2014). Using Rogers' framework, Lund & Stains (2015) demonstrated that while the individual instructor experience varies greatly across a wide range of contextual factors, instructors across three STEM disciplines relied most heavily on colleagues within their department and educational texts/websites for advice about teaching (Lund & Stains, 2015). Foote et al. (2014) similarly found that interpersonal communication networks were the primary source of diffusion of a new instructional strategy and suggested that interpersonal networks should be leveraged by change agents to further increase diffusion (Foote et al., 2014). In the diffusion and implementation of a web-based tool designed to facilitate active-learning instruction, Friedrichsen et al. (2017) also found that interpersonal communication networks were associated with a greater proportion of implementation than mass media communication (Friedrichsen et al., 2017).

Regarding CUREs, diffusion research has chiefly focused on motivation for adoption, identifying barriers to implementation, or exploring the acquisition of CURE-awareness knowledge by early adopting faculty (Dechenne-Peters & Scheuermann, 2020; Genné-Bacon et al., 2020; Shortlidge et al., 2017). Undergraduate STEM educators who were early adopters of a pre-developed CURE reported that interpersonal communication within local peer networks had a greater influence on their decision to adopt a CURE than communication from external sources, such as change agents or even DBER literature (Dechenne-Peters & Scheuermann, 2020). Yet the role of interpersonal communication networks is largely missing from CURE literature, despite Rogers' testimony of its importance in the diffusion process and his acknowledgement of this as an area of deficiency in the greater field of diffusion research (Rogers, 2003).

Research Questions

This study seeks to provide a launching point into the exploration of interpersonal interactions and peer-networks in the diffusion of innovations within a system, specifically through the context of an interdisciplinary centralized CURE as an innovative pedagogy in the system of undergraduate STEM education. Thus, this study seeks to answer the following questions: 1) what are the types and structures of networks utilized by instructors teaching a CURE within a CURE community; and 2) what is the role of the CURE community throughout the change process?

CHAPTER 2

METHODS

The Malate Dehydrogenase CURE Community

The Malate dehydrogenase CURE Community (MCC) is an NSF-funded project designed to build a community of instructors teaching protein-centric CUREs. The creators of the Community (henceforth known as the MCC primary investigators, or MCC PIs) envisioned a self-sustaining community to provide systemic support and resources to instructors who wished to teach protein-centric CUREs (Bell et al., 2017). One of the project's original objectives was to answer questions about the effects specific elements of CURE design have on student outcomes (University of San Diego, n.d.). However, the community provides a unique opportunity to investigate faculty-centric questions as well, particularly about instructor communication and the role of a peer network in the diffusion of a CURE.

Members of the MCC are biology, chemistry, and biochemistry instructors from institutions around the country, all teaching CUREs involving malate dehydrogenases (MDH). MDH is a ubiquitous group of enzymes which catalyze oxaloacetate and malate interconversions and is of particular interest in cancer research because of its involvement in mitochondrial function and metabolic regulation in various types of tumor cells (Bell et al., 2017). Because of its ubiquity and diversity, many gaps exist in the science community's knowledge of MDH, and so fundamental research is ongoing (Bell et al., 2017). This makes MDH a suitable subject to build CUREs around, as it allows students the potential to develop novel hypotheses and data, believed to be a critical element of CURE design for effective student learning outcomes (Bell et al., 2017). Instructors could design their own MDH CURE, incorporate an existing MDH CURE in its entirety, or modify existing MDH CURE modules for their own institutional context. The MCC CUREs must include the seven common elements of a CURE (see Figure 2), in which a student experiences: 1) relevance, 2) scientific background, 3) hypothesis development, 4) proposal development, 5) experimentation, teamwork, collaboration, and reproducibility, 6) data analysis and data-driven conclusions, and 7) presentation of the data (*What Is an MCC CURE? — MCC*, n.d.).

Time, money, and cognitive workload are often cited as the primary barriers to CURE adoption (Brownell & Tanner, 2012). The primary investigators (PIs) of the MCC project designed materials for instructors to reduce these barriers to MDH CURE adoption: MDH mutant clones, research protocols, instructional materials, workshops, and encouragement to collaborate with other members of the community (Bell, Bell & Provost, 2017). Participating instructors may choose to incorporate a semester-long CURE (cCURE) or a shorter, modular CURE (mCURE) (*What Is an MCC CURE? — MCC*, n.d.). They may also choose to collaborate with instructors at other institutions, facilitating cross-institution collaboration between their students (*What Is an MCC CURE? — MCC*, n.d.).

The MCC is a member of the Course-based Undergraduate Research Experience Network (CUREnet). Established in 2012, CUREnet is an NSF-funded network designed to facilitate CURE-centric networking, research, and support between instructors actively teaching CUREs and those interested in designing or adopting a CURE (About CUREnet, n.d.). Ultimately, CUREnet aims to support sustainability of widespread CURE adoption.

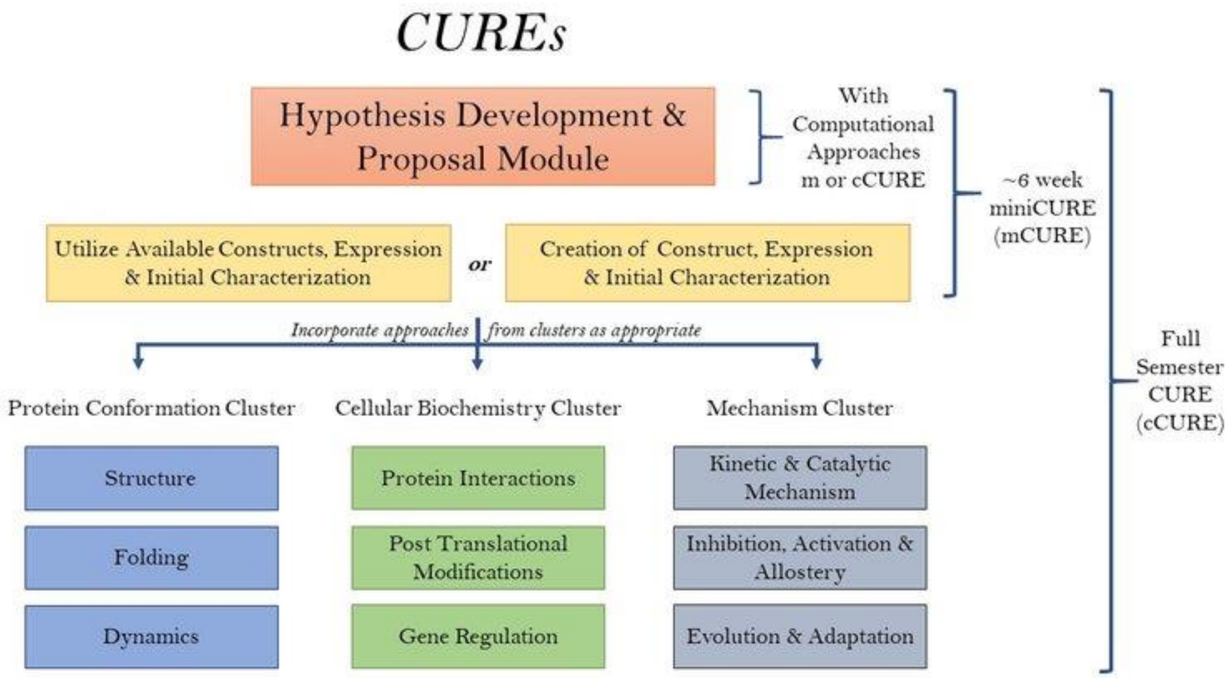

Figure 2: Creating Wet or Dry Lab CUREs with MCC Resources. From Overview: What Are MCC1.0 CUREs, OUR CUREs Community. Retrieved 22 November 2020.

In-Depth Interviews

Due to the nature of the research questions, it was determined that individual in-depth interviews (IDI) would be necessary to elucidate the nature of networks used by instructors and the communications happening within them. A semi-structured interview guide was designed to probe instructors' individual perspectives and experiences (see Appendix A: In-depth Interview Guide). IRB approval was obtained (IRB#H22009), and MCC participants were recruited using their publicly available email addresses. Twenty-four MCC instructors were sent the recruitment email and six consented to interview requests. The e-mail address of one MCC member was outdated, and thus the member could not be contacted. A second "nudge" recruitment email was sent to the remaining 17 instructors. One instructor declined to be interviewed, seven instructors consented to interviews after the second round of emails, and no response was obtained from the remaining nine instructors. Ultimately, thirteen MCC instructors consented to interview requests. All thirteen interviews were conducted via Zoom and ranged between 30 minutes and 1 hour in duration.

Participants

Because the MCC revolves around protein-centric CUREs, it is applicable for lab courses across multiple STEM disciplines: biology, biochemistry, and chemistry. Interviewees' expertise spanned all three disciplines; however, discipline information is not provided to protect the anonymity of the interviewed participants. Instructors' teaching experience ranged from three to more than twenty years, with an average of 10.2 years and mode of five years of teaching experience. Of the interviewed participants, 10 had prior knowledge of CUREs before joining the MCC. Three had no prior knowledge of CUREs prior to joining the MCC.

Instructor profiles were developed using questions in the in-depth interview, MCC materials, and publicly available information, such as institution listings on the Carnegie Classifications webpage (*Carnegie Classifications | Basic Classification*, n.d.). The MCC is a tight-knit community, and out of consideration for interview participants' privacy, "they/them" will be used as gender pronouns for all participants. Interviewees were not asked to identify their gender pronouns and did not volunteer specific pronouns; the use of "they/them" is to prevent unintentional identification of a participant.

Also due to privacy considerations, individual instructor profiles are not included in this manuscript and quotes by interviewees will not be attributed to individual instructors. Instead, instructors are categorized by the Carnegie Classification of their current institution at the time interviews were conducted. Institutions classified as doctoral/professional universities (D/PU) were categorized as master's degree granting institutions (MU) if the instructor's department offered a master's degree, or as primarily undergraduate institutions (PUI) if their department offered only bachelor's degrees. Three interviewees taught at research-intensive (R1) universities. Four instructors belonged to institutions with master's programs (MU). Three instructors belonged to primarily undergraduate institutions (PUI). Three instructors belonged to community colleges (CC).

To understand the structures and application of networks within and outside of the MCC, interview participants were categorized by their temporal cohort within the MCC (see Table 1: Description of In-depth Interview Participants). Seven interviewees joined the MCC in the first and second years of the grant, referred to as the "Early Cohort". Two joined while the MCC grant support was still active, but after the first two years. This cohort was referred to as the "Middle Cohort". Four members joined the community after grant funding support had ended and are referred to as the "Later Cohort".

Table 1: Description of In-depth Interview Participants

Description	Cohort Code	Number of Instructors Interviewed	Instructor's Prior CURE Knowledge		Percentage of Interviews Represented by Cohort
			Yes	No	
First Years	Early	7	5	2	53.8%
Grant Support	Middle	2	2	0	15.4%
After end of grant support	Later	4	3	1	30.8%

Data Analysis

The text transcripts of 13 in-depth interviews were de-identified and qualitatively analyzed using Roger's DOI as a theoretical framework in NVivo12. Each interview transcript was iteratively analyzed and coded by the PI of this study (initials: NLS). Coding consisted of individually analyzing all statements made by the interviewee and assigning a descriptive label, or "code", to each passage to capture the interviewee's intended meaning. Once coding saturation – the point when no more new codes emerged – was reached, the final codebook was established by removing those codes that were redundant or irrelevant to instructor communication and the research questions. The remaining codes represented the developed codebook. These codes were then organized by relationships between the codes, which indicated major themes present across multiple interviews. For example, the statement “I felt really alone, the first year” (R1 instructor) was coded as “Sense of Belonging” because the statement describes the absence of a sense of inclusion. The code “Sense of Belonging” was nested under the parent code “Instructor Feelings”, which was then nested within the theme of “Characteristics of Instructors”. To ensure the validity of the codes and themes NLS found emergent from the data, NLS’ coding was compared to that of SEDP, the supervising faculty member of this project. Coding comparison was conducted across seven of the 13 interviews. Instances of incongruity between NLS’ and SEDP’s coding assignments were individually assessed and resolved until both coders were in agreement.

Members of the MCC who agreed to be interviewed were assigned anonymizing numerical identifiers; example: “P1” for “Participant 1”. Some interviewees discussed specific members of the MCC who did not consent to interviews. In these cases, the non-interviewed MCC member was given an anonymizing alphabetical identifier beginning with “Person M_”; for example, “Person MA” for the first MCC member named but not interviewed. Persons who were not members of the MCC and were discussed by name in the interviews were given anonymizing alphabetical identifiers beginning with “Person E_”; for example, “Person EA”. Triangulation between interviews, MCC IUSE grant data, and MCC membership information was used to build a profile of MCC members who did not participate in interviews but were named by interviewed participants. Profiles of these named individuals included institution classification, area of expertise, and cohort within the MCC.

CHAPTER 3

RESULTS

The innovation-decision represents the intersection of four contexts: characteristics of the innovation, characteristics of the potential adopter, the characteristics of the system(s) to which the potential adopter intends to use the innovation, and the communication channels facilitating progression through each stage of the process. In this study, the MDH CURE is the innovation, the instructor is the potential adopter, their institution is the system, and peer networks are the communication channels. To understand the role of the malate dehydrogenase CURE community throughout the innovation-decision process requires exploration of each of these aspects and their interactions. Therefore, codes have been arranged into themes that loosely correlate with the stages of the innovation-decision process (see Table 2: Major Themes Found in Interviews), although some codes span multiple stages.

Data analysis is the most complex aspect of qualitative data. Because this study seeks to identify common themes, codes that appeared in less than 4 interviews (roughly 1/3 of participants) are not included in these results unless they have significant implications.

Table 2: Major Themes Found in Interviews

Theme #	Major Theme	Number of Instructors	Number of Codes	Example Quote
Theme 1	The MCC as an FLC and/or CoP	13	1,460	"It's really nice, you know, especially in a competitive world like this. It's competitive or you feel like you go to grad school, and you didn't learn enough, or you know, like you know you don't know what to do. And it's just nice to come to a community, who is so willing to help and there is just a wealth of things to learn and be part of. It's really nice." – CC Instructor
Theme 2	Characteristics of Instructors	13	386	"I did a lot of bench research before I got to a more teaching focused position." – R1 Instructor

Theme 3	Challenges	13	332	"I felt like I was drowning at a couple points." – R1 Instructor
Theme 4	Characteristics of the MDH CURE as an Innovation	13	320	"… this is a protein-centric CURE. And we're supposed to be touching on nucleic acids as well, and so we added a little bit." – R1 Instructor
Theme 5	External Resources	13	62	"Outside of the Community? um I would probably say other faculty members here as well…" – PUI Instructor
Theme 6	Identification of a Need	10	58	"I wanted to have a lab that was interesting. I was tired of having the students do a different exercise every week and I was not coming up with any biochemistry projects that I could do easily and cheaply." – MU Instructor
Theme 7	Future Planning	9	43	"One of the things that I think is one of the things we're trying to improve is maybe some of the like tracking about who's doing what, what mutants they've made, things like that." – MU Instructor

Theme 1: MCC as an FLC and/or CoP

Faculty learning communities (FLC) and communities of practice (CoP) are forms of social learning based in practice. As a community formed around teaching MDH CUREs, the MCC exhibits many of the attributes of an FLC and/or CoP. Codes that framed the MCC as an FLC and/or a CoP were grouped under the theme "MCC as FLC and/or CoP". This theme represents the most coding across interviews. Codes within this theme were grouped by categories which loosely correlate with the innovation-decision process, as described in Roger's DOI (see Table 3: Categories of Codes Within Theme 1: MCC as FLC and/or CoP, and Figure 1: The Innovation-Decision Process).

Table 3: Categories of Codes Within Theme 1: MCC as an FLC and/or CoP		
Category	Number of Instructors	Example Quote
1. Exposure to the MCC	13	"I didn't really have much background knowledge other that 'yeah, this is a great thing that you should do this. Oh, by the way, there's this community of people as well.'" – PUI Instructor
2. Appeal of the MCC	13	"I felt like I needed to work on an enzyme, and I don't really work on an enzyme, but we can easily measure its rate, so that was really the thing that pulled me in first was just the fact that I could get resources related to malate dehydrogenase which would be useful to teaching this course." – MU Instructor
3. MCC Structure	13	"We have this large group of people at diverse institutions where we could interact with each other and talk about ways to implement and engage." – MU Instructor
4. Surprised by the MCC	11	"I was thinking, they were going to just help me get set up. I didn't realize that the Community was that well-formed." – CC Instructor
5. Engages the Community	13	"My primary reliance on the MCC, as I mentioned before, was filling in all the gaps below that skeleton … like when it comes to protein expression, protein kinetics … I hadn't done that. So having the background, having the support to be able to pull off all of that and have the information, how to do all of that is, was my most heavy reliance on the MCC." – CC Instructor
6. CURE as Research	13	"And so that really got a lot of people jazzed when I first when I when I interviewed because we don't, we have a very limited number of faculty members and we have a lot of students that want to do research, and so this gives them that opportunity in a class they're already going to take." – PUI Instructor
7. MCC Annual Meetings	12	"… I didn't know what it was, [colleague] was just like 'I went to this thing and people were saying XYZ' and I was like 'what was this thing?' It was very confusing. Now that I've been to one, it's super incredibly helpful." – R1 Instructor

8. Mentoring	8	"I feel like now I kind of just run it without, you know, I know they're there and I can reach out at any time … so I kind of have an idea of what's going on, so now if I'm talking to them, it's more fine-tuning, or helping. "Oh, this person wants to do it, blah" well let me help, so more kind of the mentor role than the mentoree [sic] role." – PUI Instructor
9. Changes in MCC Over Time	9	"I feel like now we're more at the point where we're having more discussions about the science and about what we're learning about MDH whereas initially it was a lot more discussions about how to get the essays to work and technical issues and how to set up the CURE, you know how to set up the curriculum." – MU Instructor
10. MCC Expansion	13	"I know that they're completely working on those things, working on the website, working on all of these integrations and things like that, and I think that's great, I think that's more appealing for a faculty member to come in and say 'hey, we have these resources for you, and so you don't have to start from ground zero'." – PUI Instructor
11. MCC as Launch Point	13	"I mean, we just published a paper, we're about to publish another one … so it helped me get tenure and it'll hopefully help me get final promotion and now I'm gonna be submitting a new grant, so it's just been great." – PUI Instructor

<u>MCC as FLC and/or CoP: Category 1 - Exposure to the MCC</u>

Discussion of how instructors discovered or were exposed to the MCC were coded as "Exposure to the MCC". Exposure to the MCC was coded 38 times across all 13 interviews. Five instructors had a pre-existing relationship with one of the MCC PIs, and three of those five instructors indicated that they knew a PI through their undergraduate research experience, although they did not necessarily work with/for the PI. Three instructors indicated they learned of the MCC through the recommendation of a colleague; in two of those cases, the colleague was the chair of their department. Six instructors indicated that they had heard a PI present on the MCC and/or MDH CUREs at a meeting or conference, although this did not necessarily initiate entry into the community at that time. In fact, one instructor stated they felt that a CURE “would never work” at their institution due to the constraints of articulation agreements between courses at their two-year institution and those at certain four-year institutions.

MCC as FLC and/or CoP: Category 2 - Appeal of the MCC

Descriptions of why an interviewee joined the MCC, or why another individual may want to join the MCC, were coded as “Appeal of the MCC.” Appeal of the MCC was coded 104 times across all 13 interviews. The primary codes within the category included associated community, materials or funding provided, protein-centric CURE, research and scholarship, and support from an external system. Ten instructors cited the supportive community associated with the MDH CURE as their reason for deciding to implement the CURE, and thus joining the community. Seven instructors described the fact that the MCC provided materials or grant support as an incentive for joining. Seven instructors joined the community because the MDH CURE was a protein-centric CURE. Five instructors were incentivized by the opportunity to conduct research and/or the potential scholarship associated with the MDH CURE. Three instructors described recommendations to implement the CURE at their institution from an external system, such as a professional society or their department chair.

MCC as FLC and/or CoP: Category 3 - MCC Structure

Instances in which participants discussed the hierarchy or organization of people or resources within the MCC were coded as “MCC structure”. This code appeared across all institution types. The primary codes in this category included diversity of the MCC, MCC primary investigators, community hierarchy, and peer leaders within the MCC.

Instances in which participants discussed the diversity of the MCC was coded as “Diversity of MCC”. Examples of the diversity within the MCC included discipline, expertise, institution type, and teaching experience. Members of the MCC were biologists, biochemists, and/or chemists. Their training, research, and teaching experiences and interests were also quite varied, but are not disclosed here for privacy concerns. Interviewees also belonged to diverse institutions: research-intensive, doctoral/professional, masters' granting, primarily undergraduate, and community college institutions (to protect anonymity, instructors belonging to doctoral/professional universities were reclassified by the nature of their department to either MU or PUI classification). Some instructors had extensive research background, while others were highly experienced teachers. Teaching experience ranged from 3 years to more than 22 years. The code "Diversity of the MCC" appeared 25 times across 12 instructors and spanned all institution types.

The MCC primary investigators were discussed as peer leaders by ten of the 13 interviewees when asked to identify peer leaders within the community. All three PIs were referenced as leaders in a generalized sense at this point in the in-depth interviews, although some interviewees later elaborated on their perceptions of the PIs in response to another interview prompt.

The community hierarchy code was used to capture the overall organization within the community. Seven instructors described the community's organization as a top-down hierarchy, in which the PIs were the experts and leaders and the influence of members within the community was dependent on their MCC cohort and experience teaching the MDH CURE. In this structure, the PIs had the greatest influence, followed by the first cohort, then the middle cohort, and then the later cohort. Five instructors described the MCC structure as fully collaborative; the PIs, while still highly influential, were viewed more as collaborators. Three participants described the MCC as both a top-down hierarchy, generating a 25% overlap between the top-down and collaborative structure codes (Figure 3). Five instructors discussed miscellaneous structures or sub-structures within the MCC, such as internal networks formed out of institutional proximity. Three instructors felt that the MCC was unstructured in terms of people and/or information.

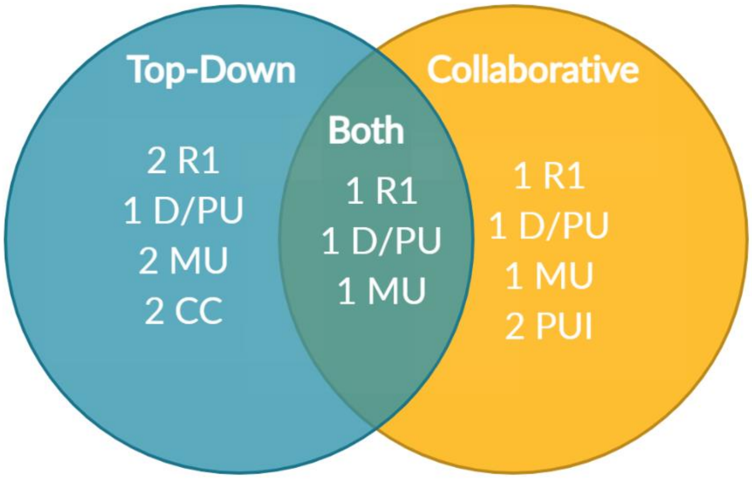

Figure 3: Instructors' Perceptions of the MCC's Internal Structure

Peer leaders within the MCC were discussed by all interviewees, primarily in response to a prompt from the in-depth interview about peer leaders within the community, but also in other contexts. Two non-PI peer leaders were identified: Person MA, a community college instructor, and person MB, a DBER expert. One of these individuals was contacted with a request for an interview but did not participate. The second was not asked for an interview, because they were the mentor of the graduate student for this project.

Code: Peer Leaders - Person MA

Person MA was mentioned 24 times by eight interviewees. Person MA was a community college instructor whom interviewees described as "innovative", "hardworking", and generally helpful. Person MA created instructional materials for other members of the community to use for implementation of the MDH CURE at their respective institutions. Three of the interviewees belonged to the same MCC cohort Person MA also belonged to. One interviewee recounted using Person MA's membership in the MCC as leverage to promote the MCC to a potential recruit. Two interviewees explicitly stated that they would not have joined the MCC and/or taught the MDH CURE if Person MA had not been involved.

> “[Person MA] definitely as someone who was very innovative and doing things with Community colleges, but also kind of doing shorter term things, did a lot.” – R1 instructor

> “[PI A] put me in contact with [Person MA], who's another … community college level person and if [they] had not gotten involved, I would have walked away. It was too complicated. Because the university-level stuff does not work at the Community college. It just it flat out does not work. It’s way too above what they can handle and [Person MA] had taken and distilled everything down into this kind of nice package, and [they] shared it all, if [they] wouldn't have shared it, I would have … left.” – CC Instructor

> “If I had questions about community college, I mean [Person MA], I don’t know if you’ve talked to [them], I mean [they’re] just spectacular and super hardworking and always had great ideas and willing to share.” – PUI Instructor

Code: Peer Leaders - Person MB

Person MB was mentioned a total of 23 times by six of the instructors interviewed. Person MB’s training is in STEM education research and belongs to the middle cohort of MCC participants. Four of the interviewed instructors discussed Person MB in the context of Person MB’s expertise in pedagogy and education research. They were described as “vital” to filling in pedagogical expertise gaps in the community, an area of expertise in which Person MB was “unique”. Two interviewees discussed co-authorship on a manuscript with Person MB.

> “I and many others in the collaborative have relied heavily on [their] detailed knowledge of pedagogical research, you know I came to the table as one of those, I’ll even say arrogant [to] people like “Oh I’ll just do a pretest and a posttest, look at me, I’m doing education research” and I now have seen over the last few years, just how immensely data driven the field has become, and how much knowledge you have to have and so [Person MB] has been a vital peer leader to all of us in. We get this mound of data from the external

> evaluator, and we all look at it like "What in the hell do we do with this?" and so [Person MB] has been really vital on that side of the equation." – PUI Instructor

> "So, each for various reasons for [Person MB], you know [their] background is in obviously education- scientific education practice, and we didn't have someone like that in the Community, so when [they] got recruited [they] kind of [were] provided- was given the job of sort of overseeing all that, and you know [they've] taken the reins quite wonderfully." – MU Instructor

> "But I would say in each case, maybe [Person MB] is the exception just because of kind of unique uniqueness of [their] background, but these are people that kind of bubbled to the surface in terms of their participation." – MU Instructor

MCC as FLC and/or CoP: Category 4 - Surprised by MCC

The code "Surprised by MCC" was used to capture interviewees' discussions of unanticipated features, events, or consequences of joining the MCC or teaching the MDH CURE. This code appeared 48 times across 11 interviews and all institution categories. For example, one instructor did not realize that MCC membership spanned the U.S.

Dissonance between the instructor's expectations and actual experience – i.e. "I expected X but what I found was Y" – were coded as "misconceptions". Of the Surprised by MCC codes, 25 were coded as misconceptions by 6 instructors. For example, one instructor expected more communication between community members.

MCC as FLC and/or CoP: Category 5 - Engages the Community

Instances in which instructors described utilizing the MCC and/or what they utilized the MCC for were coded as "Engages the Community". Community engagement was meant to specifically capture what activities or needs prompted members of the MCC to interact with other members of the community. Engages the Community was coded a total of 381 times across all 13 interviews. The primary codes within engages the community include MCC provides resources, PI interactions, MCC provides moral support, and class collaboration with other classes.

All thirteen instructors described using resources within the community. Six discussed contributing resources to the community. Resources were defined as materials, both tangible (e.g., reagents or mutants) and intangible (e.g., protocols or teaching materials), technical support and troubleshooting, knowledge or expertise, and funding.

Instances in which the instructors interacted with the MCC PIs or described the role of the PIs in the community, was coded as "PI Interactions". PI Interactions was coded across 12 interviews. The PIs were primarily characterized as knowledge providers within the community, and secondarily as collaborators. Some MCC members conducted class collaborations with the MCC PIs. The PIs attended meeting sessions with instructors' MDH CURE students, acting as a project collaborator for the entire classroom. Some of these sessions were held virtually while others were conducted face-to-face. Mentions of collaborations with the PIs were coded as "Class Collaborations with PIs" under the PI Interactions code and were coded across all institution types.

"Moral support" was defined as non-technical, positive social support. Instances of instructors discussing moral support they received from within the MCC were captured using the code "MCC Provides Moral Support". This code was captured 60 times across 10 interviews and was most discussed in relation to pedagogy and/or CURE delivery. The code spanned all institution types.

Instructors in the MCC had the opportunity to coordinate collaboration between students in their MDH CURE class and those in the classes of other MCC instructors, or with the other instructors themselves. This collaboration could take place virtually or face-to-face. Mentions of collaboration between classes was coded as "Class Collaboration with Other Classes" and appeared 31 times across 11 instructors and all institution types.

MCC as FLC and/or CoP: Category 6 - CURE as Research

The MCC incorporates research in three ways. First, students are conducting authentic research in the classroom as part of the MDH CURE. Second, instructors are now engaged as researchers conducting and overseeing fundamental MDH research. Third, the MCC collects pedagogical data in order to engage in science education research; instructors are now positioned as participants in DBER research. Discussions that framed the MCC or the MDH CURE in any of these three aspects was coded as “CURE as Research”. This code appeared 156 times across all 13 interviews. 11 instructors discussed research in the context of MDH. Ten instructors discussed the publication aspect of the research happening within the community, six discussed science education research, and five discussed how MCC participation combined teaching and research

MCC as FLC and/or CoP: Category 7 - MCC Annual Meetings

Official meetings of all MCC instructors were organized each year. The code “MCC Annual Meetings” captures discussions of these meetings. MCC Annual Meetings was coded 73 times across 12 instructors, representing all institution types. Some meetings were held face-to-face, while others were held virtually. Participants described these meetings as “valuable” and “incredibly helpful”.

MCC as FLC and/or CoP: Category 8 - Mentoring

Instances in which interviewees discussed a direct relationship that exhibited emotional support, role modeling, career guidance, skill development, or sponsorship was coded as “mentoring”. Mentoring was coded 38 times across 8 instructors and spanned all institution types. Five instructors discussed mentoring occurring within the MCC. One instructor identified themselves as a mentor to others in the MCC. Two instructors described themselves as mentors to newer members of the MCC. Two described how Person MA provided mentoring.

MCC as FLC and/or CoP: Category 9 - Changes in MCC Over Time

Descriptions of how the MCC changed over time were coded as “Changes in MCC over time”. This code was captured across nine interviews. Members discussed the ways in which their individual role within the MCC or their needs from the community changed over time, as well as changes they saw within the MCC over time.

MCC as FLC and/or CoP: Category 10 - MCC Expansion

Instances of an interviewee discussing expansion of the community, recruitment, or new members was coded as “MCC Expansion”. This code was captured across 13 interviews and spanned all institution types. Participants discussed attempts – both successful and unsuccessful – to recruit colleagues at their institutions, as well as recruiting efforts at the community-level.

MCC as FLC and/or CoP: Category 11 - MCC as Launch Point

Instances where instructors discussed new projects or new networks formed as a result of MCC membership was coded as “MCC as Launch Point”, which was coded 119 times across all 13 interviews. The MCC PIs are involved in two new grants related to CUREs. As a result, several members of the MCC are also involved in the new grants and/or recruiting efforts for those grants. The new grant(s) were discussed by seven instructors. Nine instructors discussed “launches” within their institution. Eight instructors discussed the establishment of at least one new network. Five instructors stated that the MCC facilitated new and/or more undergraduate research students working outside of class than they had previously had. Three instructors discussed expanding the MDH CURE into more classes within their institution.

Theme 2: Characteristics of Instructors

Members of the MCC represent the successful adoption of the innovation (MDH CURE) by potential adopters (the instructors). Therefore, it is helpful to examine the characteristics of the individual instructors to assess what role the MCC played for/within their various individual contexts. Categories within this theme are arranged in order of frequency and include exposure to CUREs, institution, instructor feelings, identity, professional conferences or societies, teaching philosophy, and job transition (see Table 4: Categories of Codes Within Theme 2: Characteristics of Instructors). Characteristics of Instructors was the second most coded theme.

Table 4: Categories of Codes Within Theme 2: Characteristics of Instructors

Category	Number of Instructors	Number of Codes	Example Quote
1. Exposure to CUREs	13	120	"I was not foreign to CUREs, by the time MCC came along, between my [non-MCC CURE 1] exposure and [non-MCC CURE 2] exposure, I knew and appreciated the model very much." – PUI Instructor
2. Institution	13	99	"… I just had my review and things like that, they think that [the MDH CURE] is really strengthening in the department in that aspect." – PUI Instructor
3. Instructor Feelings	13	97	"It's nice to belong to a club and that's the way I'm looking at it like." – CC Instructor
4. Identity	11	58	"…I'm not a structural biologist…" – R1 Instructor
5. Professional Conferences or Societies	7	50	"… when I would go to meetings, I've presented I think 2 posters about the MCC? So yeah, I was always talking to people either at meetings or just local colleagues or friends who, you know, from graduate school, and you know most all of them when I would tell them about it would be like "Oh I want to be a part of that, you know, that sounds pretty fun" so yeah, I definitely was promoting it as much as I could." – PUI Instructor
6. Teaching Philosophy	7	25	"I think I liked the idea of CUREs because it kind of goes along with my teaching philosophy." – PUI Instructor
7. Job Transition	7	17	"I started [a] teaching position … quite a while ago, then I switched to a position at the same institute with a little bit more of research apportionment so that's when I got involved with the CURE. So that's basically my focus of my research for now." – R1 Instructor

Characteristics of Instructors: Category 1 - Exposure to CUREs

Before an instructor can consider adoption of a CURE or joining a CURE community, they must first become aware of the existence of CUREs as a pedagogy, the specific CURE they wish to implement, and the community surrounding it. The code "Exposure to CUREs" was used to capture instances where instructors discussed their initial awareness of or exposure to CUREs, as well as the level of their CURE knowledge and their prior experiences with CUREs. Exposure to CUREs was coded 110 times across all thirteen instructors.

Code: CURE Knowledge

CURE Knowledge was coded 23 times across 13 interviews. Participants' descriptions of their knowledge of CUREs prior to entering the MCC was categorized on a spectrum of "Very Knowledgeable", "Moderate Knowledge", "Limited Knowledge", or "No Prior Knowledge" based on their previous CURE activity (see Table 5: MCC Members' Prior CURE Knowledge). Figure 4: Spectrum of CURE Knowledge illustrates this spectrum of CURE knowledge, which is based on the knowledge stage of the innovation-decision (Rogers, 2003) and lists possible qualifying activities. Interviewees did not have to achieve each listed activity but had to meet at least one of the qualifications for a category.

Table 5: MCC Members' Prior CURE Knowledge

Level of Prior CURE Knowledge	Instructors
Very Knowledgeable	2
Moderate Knowledge	6
Limited Knowledge	3
No Prior Knowledge	2

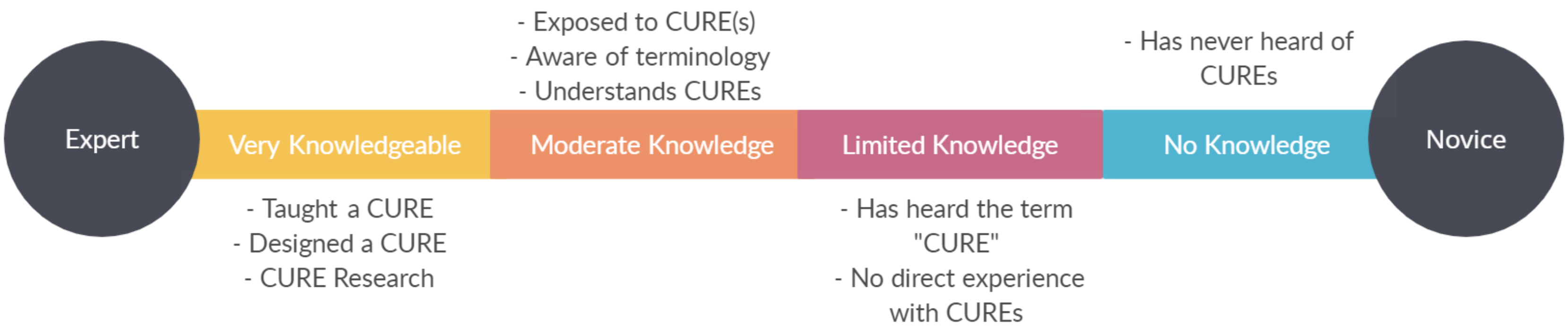

Figure 4: Spectrum of CURE Knowledge

Very Knowledgeable

Two instructors had extensive experience with CUREs prior to joining the MCC. The first was a PUI instructor who had taught CUREs. They had also been involved with another developed, centralized CURE with an active community which had given them an appreciation of the CUREs.

The second instructor was an MU instructor who was first exposed to CUREs and an MCC PI as an undergraduate. This instructor had incorporated CUREs into several of their laboratory courses and had taught them for several iterations.

Moderate Knowledge

Six of the 13 instructors had moderate prior knowledge of CUREs. An R1 instructor was exposed to the concept of CUREs through a DBER faculty member at their institution. A community college instructor had heard of CUREs via talks given by one of the PIs at “different meetings”. An MU instructor was familiar with CUREs because their post-doc mentor had done a national CURE.

Another R1 instructor had been aware of CUREs and had been involved with projects related to other CUREs. They wanted to incorporate CUREs in their lab courses but been unable to CUREs that fit their specific needs. They had also encountered resistance within their department when they had previously tried to institute a different CURE.

An MU instructor learned about CUREs through a colleague in the same department. Initially the interviewee had limited knowledge of CUREs, but their colleague taught a CURE which became a “hugely popular” course and inspired the interviewee to implement CUREs into as many of their classes as possible. This occurred around the same time the MCC was recruiting.

> “Yes, I knew I knew that term, but I didn't quite know everything it entails. Like I just I kept going “oh it’s like a big project” and trying to work a lot, so I just was like ‘eh’.” – MU Instructor

Limited Knowledge

Three instructors stated that they had very limited knowledge of CUREs. A PUI instructor stated that they had heard of CUREs through one of the PIs. The instructor was familiar with the term “CURE”, had a general sense of what a CURE was, and felt that CUREs fit their teaching philosophy, but had never investigated further. A community college instructor was exposed to CUREs at a biology teaching conference. Another attendee at the conference spoke to the interviewee about CUREs and recommended them to CUREnet, where they eventually discovered the MCC.

> “Nothing. I guess I shouldn't say nothing I knew it was kind of out there only because of [prior interactions with PI] and things like that, but prior to coming to [this institution] I hadn't really looked at it whatsoever.” – PUI Instructor

A second community college instructor had limited knowledge of CUREs. They were exposed to CUREs (and subsequently CUREnet and the MCC) when their department chair recommended they attend a CURE conference.

No Prior Knowledge

Two instructors stated that they had no knowledge of CUREs prior to joining the MCC. One was an R1 instructor who learned of CUREs when their department chair introduced the MCC grant to their department to recruit instructors at the behest of an MCC PI.

> “Nothing at all. That was really my first interaction with CUREs, through the grant…” – R1 Instructor

The second instructor with no prior knowledge of CUREs was a PUI instructor who had considered incorporating authentic research into their laboratory courses but had not been exposed to CUREs.

> "I mean I guess I had thought about doing stuff like this; I teach a biochemistry course and I had more research-based lab for that. And I had wanted to do it, but I was, I certainly wasn't familiar with the acronym CURE, I had conceived this idea to make the laboratory, you know, real research but you know in terms of a mechanism or the application that I hadn't really been able to do that yet in a very formal way." – PUI Instructor

Code: Other CUREs

Instances where instructors discussed any CURE other than the MCC CURE were coded as "Other CUREs". Other CUREs were coded a total of 20 times across 7 instructors. Two community college instructors discussed CUREnet, a network that supports the development, implementation, and investigation of CUREs (*About CUREnet*, n.d.). The CUREnet website (http://serc.carleton.edu/curenet) currently features 45 CURE listings.

> "So, my department chair had mentioned that [CUREnet] meeting; they want instructors to get involved in the student research and they had mentioned that, 'You know, the MDH CURE is a good one, if you're interested.'" – CC Instructor

Three instructors discussed self-developed CUREs. An MU instructor intended to teach a CURE revolving around their own research projects, and in fact did use that project for half a semester and the MDH CURE for the other half of the semester. An R1 instructor discussed an upper-level course at their institution that taught instructor-dependent CUREs that differed across each section of the course. A community college instructor began developing their own CURE, but halted development once they joined the MCC.

Two instructors discussed the Science Education Alliance-Phage Hunters Advancing Genomics and Evolutionary Science Program (SEA-PHAGES). In the SEA-PHAGES CURE, students explore phages in soil samples, collecting genomic and bioinformatic information (SEA-PHAGES | Home, n.d.)(SEA-PHAGES | Home, n.d.). An R1 instructor discussed the structure of

SEA-PHAGES in comparison to the MCC; they wanted a less computational-based CURE. A community college instructor discussed previous involvement with SEA-PHAGES projects.

The Genomics Education Partnership (GEP) was discussed twice by one R1 instructor. The GEP is a nationwide CURE community that supports CUREs based in genomics and bioinformatics (*About | Genomics Education Partnership*, n.d.). The instructor wanted to teach CUREs but wanted a CURE that was less computational than those in the GEP.

Two instructors discussed the Biochemistry Authentic Scientific Inquiry Laboratory (BASIL). In the BASIL CURE, students analyze proteins whose structure is characterized but function is not (*BASIL (Biochemistry Authentic Scientific Inquiry Laboratory)*, n.d.). An R1 instructor discussed BASIL in comparison to the MCC, and an MU instructor discussed encountering in the MCC previous contacts from BASIL.

Characteristics of Instructors: Category 2 - Institution

Information about instructors' institutions that was revealed in interviews was coded as "Institution". The most common codes were related to institutional change and included Institutional Support and Institutional Resistance to Change. The most common code was institutional change, which was coded across 11 interviews. Ten instructors described their institution as supportive of change, CUREs, and/or the MDH CURE. Eight instructors described resistance to change within their institution, primarily from colleagues not involved in teaching the MDH CURE.

Characteristics of Instructors: Category 3 - Instructor Feelings

Descriptions of instructors' emotions were coded as "Instructor Feelings". "Feelings" were defined as thoughts, perceptions, or language with an emotional component. The two most common codes were "sense of belonging" and "confidence". Sense of belonging was used to capture the sense of integration, or the lack thereof, into the MCC and appeared 70 times across all 13 interviews. The code “Confidence” captures instances in which instructors described belief in their ability to implement or teach the MDH CURE, participate in the community, engage the community, etc. The lack of confidence was captured under the code “uncertainty” in the “Challenges” theme. Confidence was coded 31 times across 8 instructors and spanned all institution types.

Characteristics of Instructors: Category 4 - Identity

The code “identity” was used to capture instances in which instructors described an aspect of their personal or professional identity. The code appeared 58 times across 11 interviews and spanned all institution types. To protect interview participants’ identities, a detailed breakdown is not presented for all subcodes, but included by discipline (ten instructors), miscellaneous (six instructors), teacher (three instructors), and researcher (three instructors).

Characteristics of Instructors: Category 5 – Professional Conferences or Societies

More than half of the instructors interviewed discussed membership to other professional societies and/or attending conferences related to science and scholarship. Six interviewees discussed involvement with named professional societies. Three of the interviewees discussed nonspecific national meetings.

Characteristics of Instructors: Category 6 - Teaching Philosophy

Instances in which instructors described their philosophy or beliefs about teaching and/or learning were coded as “Teaching Philosophy”. Instructors were also specifically asked to describe their teaching philosophy as part of the in-depth interview. This code appeared 40 times across all 13 interviews. Nine instructors reported using active learning strategies. Four instructors described their teaching style as requiring students to apply knowledge, rather than rote memorization. Four instructors described experiential learning, or “learning science by doing science”. Four instructors had miscellaneous teaching philosophies, including two who described their teaching as “inclusive”, using multiple modes of instruction for diverse learners.

Characteristics of Instructors: Category 7 - Job Transition

Instructors' description of a job transition within the context of the MCC or MDH CURE was coded as "Job Transition". The code appears 25 times across 7 instructors and spanned all institution types except community colleges.

Theme 3: Challenges

The adoption of an innovation carries inherent risk in the form of uncertainty and unintended consequences. Understanding the role of the MCC throughout the adoption process requires an examination of the barriers to successful implementation, and what strategies instructors used to mitigate those barriers. Instances in which instructors discussed challenges they experienced within the MCC or with the MDH CUREs were coded as "challenges". The challenge code appeared 381 times across all 13 interviews (see Table 6: Categories of Codes Within Theme 3: Challenges). This code also spanned multiple themes.

Table 6: Categories of Codes Within Theme 3: Challenges

Challenge	Number of Instructors	Number of Codes	Quote
1. Uncertainty	13	138	"I mean, I felt like probably that first year I wasn't super prepared, but who can be prepared, right?" – PUI Instructor
2. Workload	10	34	"It is a lot of work. It's a lot of work to run one of these. So, people who are doing this are really dedicated. Kudos to anybody that does it [laughs]. It's a lot of work." – CC Instructor
3. COVID-19	9	28	"… having the Community there to be like "yeah it sucks I'm having the same problem" is really helpful because I think if I was if I had had to go through the pant like switching the CURE remotely during the pandemic, for example, if there wasn't a Community like [PI A] who was showing us like tutorials of how to do these bioinformatics, I would have been like nope! I don't know what I would have done…" – R1 Instructor
4. Student Perceptions	4	8	"It's very uncomfortable for them, so I think it's changed my – this year I've tried more uncomfortable

			labs than I've ever tried before; I've been doing all kinds of new stuff that I don't know how it works and we're just figuring it out together and the students are not happy with me about it but I am proceeding anyway, because I know there's learning happening and I'm trying to let it go." – CC Instructor
5. Budget & Supplies	7	7	"… it was easier to get the physical resources I need to do, needed to do research, based on my project and much harder to find the things I needed for MDH. So, the main the main issue, to get down to it, was finding enough spectrophotometers to be able to assay the protein." – MU Instructor

Challenges: Category 1 - Uncertainty

Instances in which instructors described uncertainty in the MDH CURE, the MCC, or their abilities related to either were coded as "uncertainty". This code appeared 49 times across all 13 interviews. The most common codes in this category were inefficient or lack of structure, unique institutional context, unfamiliar with MDH, lack of belonging or support, schedule conflicts, information overwhelm, project silos, and DBER challenges.

Eleven instructors described an ineffective or lack of structure within some aspect of the MCC, particularly onboarding for new members. Six instructors described issues that arose because of a unique institutional context and the lack of similar institutions within the MCC. Eight instructors cited a lack of familiarity with MDH as a challenge. Three instructors described a lack of belonging or support. Three instructors described difficulty scheduling collaboration with their colleagues within the community. Three instructors described feeling overwhelmed by the sheer number of resources and information available to them. Three instructors stated that project silos, or the lack of visibility to see what kind of projects other members of the community were working on, was a challenge. Two instructors stated that the initial lack of a DBER expert within the community was a challenge.

Challenges: Category 2 - Workload

The large amount of time and effort involved in overhauling a course and implementing a new curriculum are established barriers to CURE implementation (Brownell & Tanner, 2012; Govindan et al., 2020). Ten instructors described implementing and/or teaching the MDH CURE as work-intensive or faced difficulties due to an already heavy workload. COVID-19 disrupted the research happening in the CURE classroom and created the challenges associated with transitioning an experiential curriculum to remote instruction.

Challenges: Category 3 - COVID-19

The COVID-19 pandemic created major disruptions across STEM, but especially in academia. Nine instructors discussed the challenges associated with COVID-19 and/or its impacts. One instructor stated that the MCC helped mitigate the emotional stress associated with working/teaching during the pandemic.

> "One of the conferences we had, the one that happened over the pandemic, the first year, the pandemic so 2020. That one was particularly helpful, I think, because people were able to share "how did I adapt this for online use?" and also there were people there who were in situations like me who had young children who were home with them and early in their career or being at work-- you know I hate to say this, but women -- women are often asked to take on more admin responsibilities. So, one of the different like separate from the CURE, but the Community provided a source of like I want to say comisery [sic], but like the understanding that you're not alone. So yeah that conference I talked with a few different women who were just like "this is so hard-- not the CURE itself, but like teaching right now is so hard" and like sharing our experiences and that you know didn't change how I taught the CURE, [but] it did like make me feel like "Okay, at least it's not just me". You know yeah that part was nice." – Instructor [institution withheld to protect identity]

Challenges: Category 4 - Student Perceptions

CUREs represent innovation and paradigm shifts not only for instructors and institutions, but also students. Despite the benefits to students, student resistance and negative perceptions of active-learning strategies is a known phenomenon in science education literature (Deslauriers et al., 2019; Park et al., n.d.; Tharayil et al., 2018). Five instructors discussed student resistance to the CURE or negative student perceptions of the CURE as a challenge. This challenge was at least partially mitigated by the instructors' perceived benefits of the CURE to students and/or themselves.

Challenges: Category 5 – Budget and Supplies

The cost and amount of resources necessary to implement a CURE are known barriers to CURE adoption (Brownell & Tanner, 2012; Govindan et al., 2020). Seven instructors described budget and material supply constraints as challenges. For most of the instructors, this challenge was the greatest prior to exposure to the MCC, however one instructor discussed difficulty obtaining analytical equipment. Most instances of cost or supply issues were mitigated by the community.

Theme 4: Characteristics of the MDH CURE as an Innovation

Characteristics of the innovation – in this case, the MDH CURE – influence how successfully an innovation is adopted and, ultimately, diffused (Rogers, 2003). The main categories of codes within this theme include exposure to CUREs, pedagogy, student impacts, and CURE diffusion (see Table 7: Categories of Codes Within Theme 4: Characteristics of the MDH CURE as an Innovation).

Table 7: Categories of Codes Within Theme 4: Characteristics of the MDH CURE as an Innovation			
Category	Number of Instructors	Number of Codes	Example Quote
1. Pedagogy	13	115	“I think university people think everybody understands what they're talking about and they think that “oh there's, they have freshmen students who can do X, Y and Z.” And they're not realizing Community college freshmen students are not the same as university level freshman students and there's a difference, there's a real difference between them, and our resources are totally different. So, I don't have all the equipment and I’m stuck with articulation; I can’t just stop everything and do – a CURE changes the whole curriculum because of it, so I mean they're aware of those things, I think they're aware they’re in the background, but they don't realize like the hurdles then become really big.” – CC Instructor
2. Student Impacts	11	53	“… students, they take it more seriously when they see we are really doing something different ... Talking to students at a different institution; they never had this experience before, so it's kind of interesting to them. I can see their motivation, it's a lot better.” – R1 Instructor

Characteristics of the MDH CURE as an Innovation: Category 1 - Pedagogy

Innovations are more likely to be adopted if they are observable while in use by others and can be adapted (reinvented) to the potential adopter’s individual context (Rogers, 2003). To examine the fidelity of implementation of the MDH CURE, the code “pedagogy” was used to capture instances in which instructors discussed how they taught the MDH CURE, such as their curriculum or course structure. The code pedagogy appeared 115 times across all 13 instructors. Instructors primarily described the course transition from the original curriculum to the MDH CURE and how to set up the CURE curriculum, including duration of the CURE (cCURE or mCURE).

<u>Characteristics of the MDH CURE as an Innovation: Category 2 - Student Impacts</u>

The primary motivation for CURE adoption is often attributed to students' learning outcomes. Instructors' discussions of how the MDH CURE or the instructor's membership in the MCC impacted their students were coded as "Student Impacts". This code appeared 53 times across 11 instructors and all institution types. Instructors primarily described changes in students' learning, motivation, and interest in conducting research.

Theme 5: External Resources

MCC instructors used existing networks and individuals outside the MCC while teaching the MDH CURE, as well as their own tangentially related experiences. External resources were referenced a total of 62 times across all 13 interviews (see Table 8: Categories Within Theme 5: External Resources). The most referenced external resource was instructors' existing contacts among colleagues. Categories of code within this theme included the same institution, different institutions, and didn't use external resources.

Table 8: Categories within Theme 5: External Resources

Category	Number of Instructors	Number of Codes	Example Quote
1. Same Institution	5	9	"And I do have my mentor, my faculty mentor at [my institution] is also really big on this, and [they teach], [they do] not teach this lab or anything like that, but [they teach] chemistry courses using active curricula like this, and so if I ever had questions, I would just ask [them]." – R1 Instructor
2. Different Institution	3	5	"I discussed it with my couple of my colleagues at [previous institution], the other two sort of formally designated [same discipline]." – MU Instructor

3. Didn't Use External Resources	4	4	"Almost everything I got was from the community. I would say it's hard for me to even, I don't want to say that everything was from the community but … because I don't want to make that declarative statement, but I would say that almost everything was, in terms of resources, in terms of people, in terms of reagents, yeah." – PUI Instructor

External Resources: Category 1 – Same Institution

Institutions are not created equally. Some may have more resources than others, including colleagues in the same department or college/school. Five instructors discussed using colleagues at their institution as a resource to implement or teach the MDH CURE. Three instructors reported using colleagues within their own department. One instructor used both colleagues within their department and within other departments as resources.

External Resources: Category 2 – Different Institution

Three instructors reported using colleagues at institutions other than their own. One instructor used a colleague at an institution in a different region to create a product to facilitate students' virtual interaction with MDH structure and mutations. Another instructor discussed being able to get resources from a nearby institution not affiliated with the MCC. The third instructor discussed using two colleagues at an institution they were previously employed at to obtain information about "class management techniques" and project-specific tools. This instance of relying on a pre-existing network from a previous place of employment represents 3% of all external resources used, and 40% of all codes referencing the use of an institution other than the instructor's current institution. Institutions other than the instructor's current place of employment represented 8% of external resources discussed by instructors.

External Resources: Category 3 – Didn't Use External Resources

Four participants reported they did not use external resources outside of the MCC to implement or teach the MDH CURE. Rather, they stated that most, if not all, of the resources used were within the MCC.

Theme 6: Identification of Need

In Rogers' (2003) DOI framework, adoption of an innovation requires that potential adopters have not only knowledge of the innovation, but also a need (or a problem) which the innovation fulfills or solves. If there is no such application for an innovation, the adopter is unlikely to engage in all the stages of the innovation-decision that result in adoption or may reach the decision stage and decide to reject the innovation. Instances where instructors discussed why they needed, or perceived that they needed, a CURE and/or the MCC were coded as "Identification of Need" (see Table 9: Categories within Theme 6: Identification of Need). Identification of Need was coded 58 times across 10 interviews and all institution types. 3 instructors did not explicitly identify a specific need.

Table 9: Categories within Theme 6: Identification of Need

Category of Codes	Number of Instructors	Number of Codes	Example Quote
1. Dissatisfied with current curriculum	6	8	"I was at the time doing my own research project and teaching labs, lab courses and finding that I didn't have enough time to do everything and also really frustrated with those lab courses, where it was a, you know, the same experiment you've done for years and years and years and it you know it just felt like a lot of busy work." – R1 Instructor
2. Changed job role or position	4	4	"Prior to me coming here, we had a whole bunch of different faculty members that were just temp faculty that would teach a very traditional [discipline] lab and so last

			year was my very first year, and so I implemented CUREs basically right off the bat." – PUI Instructor
3. Needed protein-centric CURE	4	4	"But none of the proteins I'd worked on were really enzymes, so I like I'd worked on [research topics] which don't as easily translate to an enzyme activity essay, and so that was what I felt like I needed for the class to match up the course content with like the lab content with the course content." – MU Instructor

Identification of Need: Category 1 – Dissatisfied with Current Curriculum

Building on Rogers' DOI, Andrews and Lemons (2015) propose that dissatisfaction with their curriculum or teaching is a prior condition that is necessary for college biology instructors to initiate change in their teaching, although dissatisfaction alone is not sufficient (Andrews & Lemons, 2015). The code "Dissatisfaction with Current Curriculum" was used to capture instructors' dissatisfaction with the curriculum they were teaching in their course prior to implementing the MDH CURE. The code appeared eight times across six instructors and spanned all institution types except community colleges.

Identification of Need: Category 2 – Changed Job Role or Position

As noted previously, dissatisfaction with curriculum or teaching alone is not enough to initiate change. Changing positions within the same institution or changing institutions altogether can represent an opportunity for the implementation of an innovation such as the MDH CURE. The code "Changed Job Role or Position" was used to capture instances in which instructors discussed such a change. The code was captured 4 times across 4 interviews and two institution types: R1 and PUI.

Identification of Need: Category 3 – Needed Protein-centric CURE

There is a lack of network protein-centric CUREs (Bell et al., 2017). This lack of biochemistry CUREs creates a potential need for instructors who wish to teach a network CURE but whose course objectives include concepts related to proteins. The code “Needed Protein-centric CURE” was captured four times across four interviews and spanned all institution types except R1.

Theme 7: Future Planning

Implementing the innovation is not the final stage in the adoption of an innovation. In the confirmation stage, the potential adopter continues to evaluate the innovation and its role in their individual context (Rogers, 2003). Adopters of an innovation (such as the MDH CURE) may choose to continue using the innovation, or they may discontinue its use. In addition, one of the characteristics of a community of practice (such as the MCC) is investment in the recruitment and development of future members (Wegner, 1999).

The “Future Planning” code captures instances in which the participant displays forward planning: ways in which they intend to change their course, change the MDH CURE, or changes they wish to see in the MCC. The code is indicative of intent to continue using the innovation (the MDH CURE) and/or invest in the MCC. The category “instructor plans” captures instructors’ intent to continue teaching and/or modifying the MDH CURE to fit their individual context. The category “MCC plans” captures instructors’ intent to continue involvement with the MCC, or changes currently happening within the MCC. This code appeared across 9 interviews and spanned all institution types.

Table 10: Categories within Theme 7: Future Planning			
Category	Number of Instructors	Number of Codes	Example Quote
1. Instructor Plans	5	19	“One thing I love that I haven't yet had a chance to do but I’d like to is actually collaborate with another institution, so that the students are sharing their data among other students, which I think would help them feel like they have more ownership of the project.” – R1 Instructor
2. MCC Plans	8	16	“I think that needs to be much more user like a user-friendly interface, a clear understanding that there's a whole support system with like people's names and contact information with what they do so you can find the person that best fits the needs of your institution, I think that would be super helpful. From the people I spoke with at conferences, who were in the same boat as me -- they all said exactly that same thing, like that would have been helpful.” – R1 Instructor

Future Planning: Category 1 – Instructor Plans

The code “instructor plans” captures instructors’ intent to modify or supplement the MDH CURE. The code appears 19 times across 5 interviews and spans all institution types except MU. The most common codes involved future collaboration between classes at another institution, usually within the MCC.

Future Planning: Category 2 – MCC Plans

The code “MCC plans” captures instructors’ continued involvement in the MCC, and the community’s investment in its own future. This code appeared 16 times across 8 interviews and spanned all institution types. The two most common codes were closely related: organize information and onboarding. Four instructors stated that information in the community lacks centralization but indicated that the community is working towards building a “hub” to address this issue. Three instructors stated the community lacked structured “onboarding” infrastructure to facilitate effective integration of new members into the MCC, and that the community was again working towards addressing this issue.

CHAPTER 4

CONCLUSIONS

CUREs are a high impact evidence-based teaching practice. However, demonstrating the empirical evidence of a curriculum or teaching practice is not sufficient alone to motivate change in instructional practice; rather, testimonials and other personal communications are far more persuasive (Andrews & Lemons, 2015; Rogers, 2003). To support the widespread adoption of high impact curricula such CUREs, agents of science education reform must understand the characteristics of instructor communication networks, and the role those networks play throughout the change process.

The Types and Structures of Networks Utilized by MCC Instructors

The widespread adoption, or diffusion, of an innovation such as a CURE is driven by interpersonal communication (Rogers, 2003). Positive messaging about the innovation transmitted via social networks can initiate awareness of the innovation's existence, as well as persuade members of the network to use the innovation. This facilitates a critical mass of adopters, and further diffusion and adoption of the innovation becomes self-sustaining.

Conclusion 1: The MCC is Both a Faculty Learning Community and a Community of Practice

The Malate Dehydrogenase CURE Community was envisioned by its original creators as a collaborative community of chemists, biochemists, and biologists united by the shared experience of teaching protein centric MDH CUREs. At the time of the community's creation, no large-scale biochemistry CUREs existed, although the genomics-based GEP and SEA-PHAGES CUREs had seen relative success (Bell et al., 2017). The MCC was formed to facilitate the development and sustained adoption of protein centric CUREs, as well as to examine the impacts of CURE length and collaboration (Eddy et al., 2018).

Although the terminology was not used in the initial grant, this mission statement positions the MCC as a faculty learning community (FLC). An FLC is defined as a small group of faculty from across multiple disciplines, united in a program of practice that is intended to enhance teaching and learning, provides activities to facilitate learning, professional development, and foster a sense of community; and lasts at least one year (Cox, 2004, 2017). Cox proposes that FLCs may be divided into two categories: cohort-focused FLCs and issue-focused FLCs. Cohort FLCs are those that address the professional development and scholarship of teaching for a cohort of faculty that have a shared need specific to that cohort, such as an FLC for junior faculty (Cox, 2017). Issue-focused FLCs are united by a curriculum to address special issues.

While the MCC is arguably not a small group – there were 22 MCC members as of the last year of grant support, and the community continues to expand – it meets all other FLC criteria. Workshops, annual meetings, and activities were supported through grant funding for three years. Although grant support has since ended, members continue to be united by the practice of teaching an MDH CURE and undertake activities to improve their teaching and learn about pedagogy. The MCC continues to facilitate learning and professional development through new projects, networks, and activities. The MCC fosters a sense of community within its members, as evidenced by ubiquity of the sense of belonging code among these thirteen members.

> "So, I started by independently at that CUREnet circ kind of writing my own project, I never finished writing that, like I don't submit to that because I feel like I'm part of the MDH community and whatever I do, I kind of want to do with them." – CC Instructor

Because teaching experience, institutional context, and individual demographics within the MCC are so diverse, and recruitment into the MCC is ongoing, it best fits the definition of an issue-focused FLC, rather than that of a cohort-focused FLC – the issue being the implementation and practice of effectively teaching MDH CUREs.

At the same time, the MCC is also a scientific community of practice (CoP). Wenger defines a CoP as “a group of people who share a concern, a set of problems, or a passion about a topic and who deepen their knowledge and expertise in this area by interacting on an ongoing basis” (Wegner et al., 2002, p4). Social learning theories situate learning as a social process; that is, shaped by experience and interactions with other individuals (Wegner, 1999). Social learning theory is built on four components: meaning, practice, community, and identity. “Meaning” refers to the ability to experience life and the world as meaningful, at the individual or collective level; this ability is malleable and changing. “Practice” refers to shared resources, frameworks, and perspectives which can sustain engagement. “Identity” refers to the dynamic concept of who an individual is and their personal history within the context of the community. “Community” refers to the social configurations and structures which define what enterprises are worth pursuing and participation is recognizable as competence.

Figure 5: The Components of Social Theory of Learning. Adapted from Communities of Practice: Learning, Meaning, and Identity (pg 4) by E. Wegner, 1999, Cambridge University Press. Copyright 1999 Cambridge University Press.

Communities of practice place the emphasis on learning through practice or "learning as doing". This context has implications for learning at the individual, community, and organizational level. At the individual level, learning is a matter of both engaging in and contributing to the community. At the community level, learning consists of refining the practice and ensuring robust, viable future generations of members. At the organizational level, learning means sustaining interconnected communities of practice which supply the organization with knowledge, thus sustaining the organization's status as effective and valuable (Wegner, 1999). Communities of practice are sustained through three dimensions: mutual engagement, joint enterprise, and shared repertoire (Wegner, 1999). Mutual engagement involves engaged diversity, doing things together, forming relationships, social complexity, and performing community maintenance. Joint enterprise refers to the negotiated enterprise of the community, mutual accountability, interpretations, rhythms, and local response. A shared repertoire is composed of the stories, tools, historical events, actions, discourses, concepts, and styles that occur within the community.

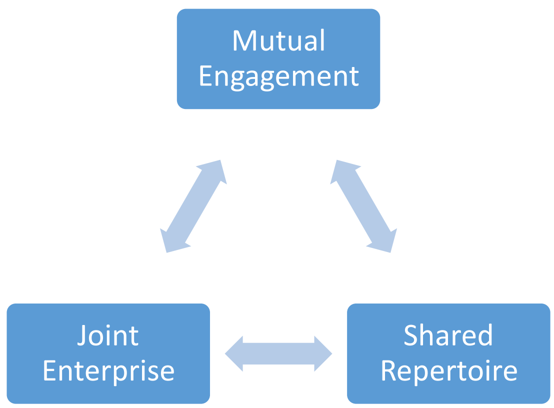

Figure 6: Dimensions of practice as the property of a community. Adapted from Communities of Practice: Learning, Meaning, and Identity, by E. Wegner, 1999, p. 72. Copyright Cambridge University Press 1998.

The MCC represents a scientific community of practice around malate dehydrogenase research. MCC members engage in all three sustaining aspects of a CoP, as demonstrated by the codes under the theme "MCC as FLC and/or CoP" (see Figure 7). The MCC facilitates collaborative activities and relationships, is socially complex, and its members participate in the maintenance of the community. Members of the community have been heavily involved and invested in the community's development, maintenance, growth, and building a shared repertoire. Members support the development and promotion of sustainable protein-centric CUREs and conduct fundamental research into malate dehydrogenases. Participants routinely engage in collaborative inquiry in which they exchange information about MDH, including novel experiments and findings.

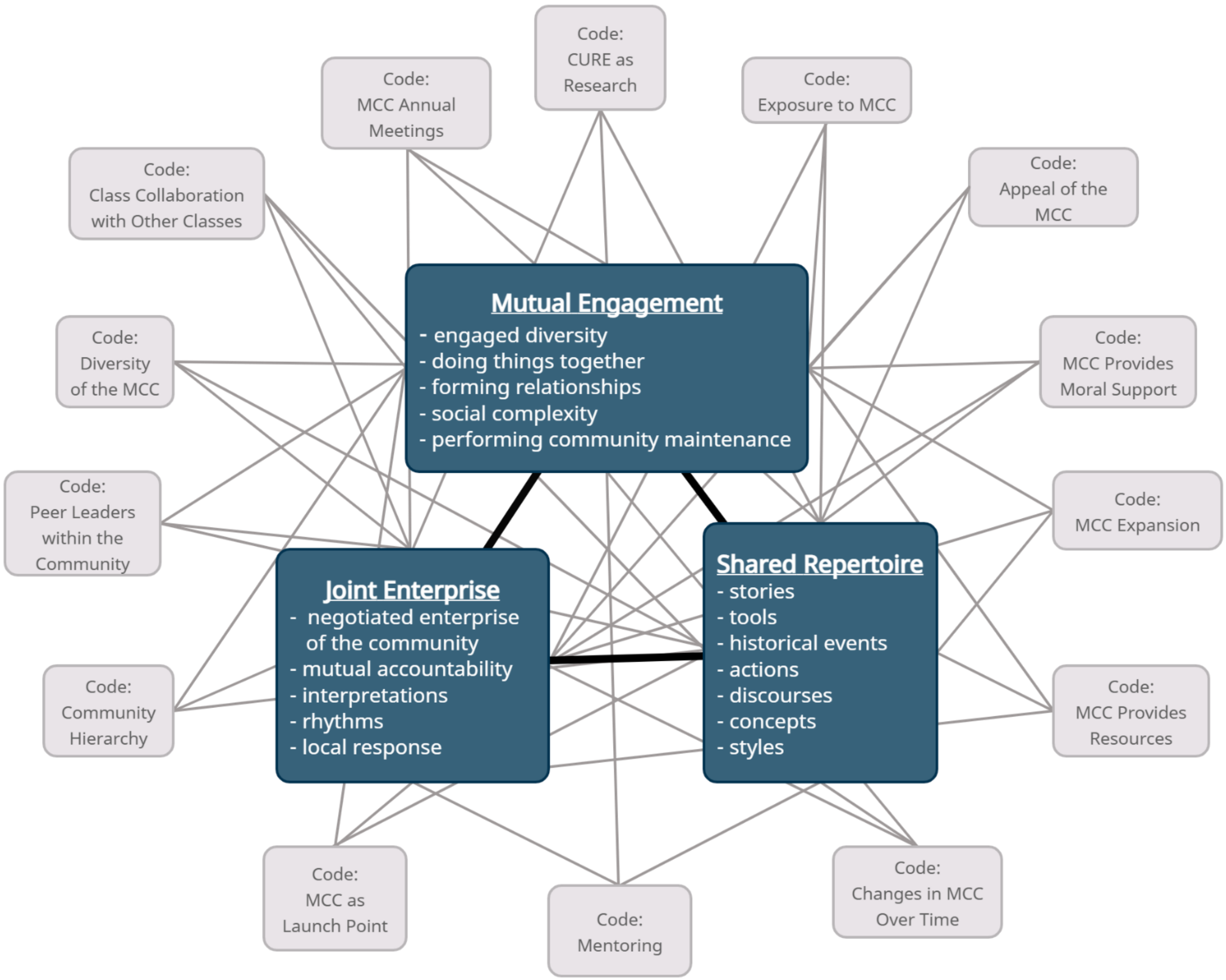

Figure 7: MCC as FLC and/or CoP codes and how they relate to Wegner's (1999) dimensions of practice as the property of a community. Each gray line represents a relationship between a code (gray boxes) and one of the three categories of major characteristics of a community of practice (blue boxes). Bold black lines represent the relationship between the three categories of major characteristics of a community of practice.

Conclusion 2: Instructors Have Differing Perceptions of the Internal Structure of the MCC

While the MCC is both an FLC and CoP, members of the community have differing perceptions of the community's internal structure. Nearly 54% of the instructors interviewed described the MCC's internal structure as a top-down hierarchy, in which the MCC PIs had the greatest level of influence, MDH expertise, and leadership (see Figure 8). Community members were then arranged into a hierarchy depending on their experience working with MDH and/or teaching the MDH CURE; this stratified the community members into a cohort-based hierarchy in which the initial cohort had the greatest influence, followed by the middle cohort, then the later cohort. This top-down hierarchy structure is supported by the interviewees' perceived peer leaders within the community: all but one of the individuals named as peer leaders within the community belonged to the initial cohort, and the exception was due to their high level of subject-matter expertise.

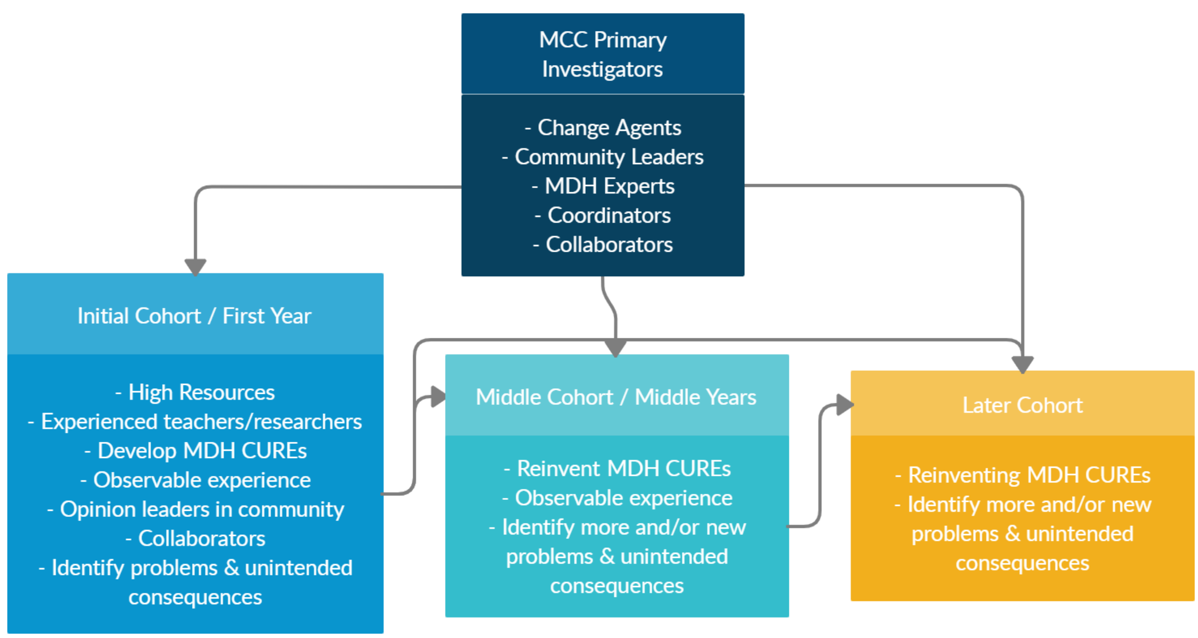

Figure 8: Top-down hierarchy within the MCC as described by ~54% of participants

Nearly 40% of the MCC participants interviewed described the internal structure of the MCC as collaborative. In this structure, the MCC PIs were the MDH experts, but numerous collaborative relationships were established between individual members as well as with the PIs (see Figure 9). Some collaborative relationships had higher sustained activity than others, and subnetworks formed based on mutual projects, institutional context, or proximity, but these relationships were not hierarchical.

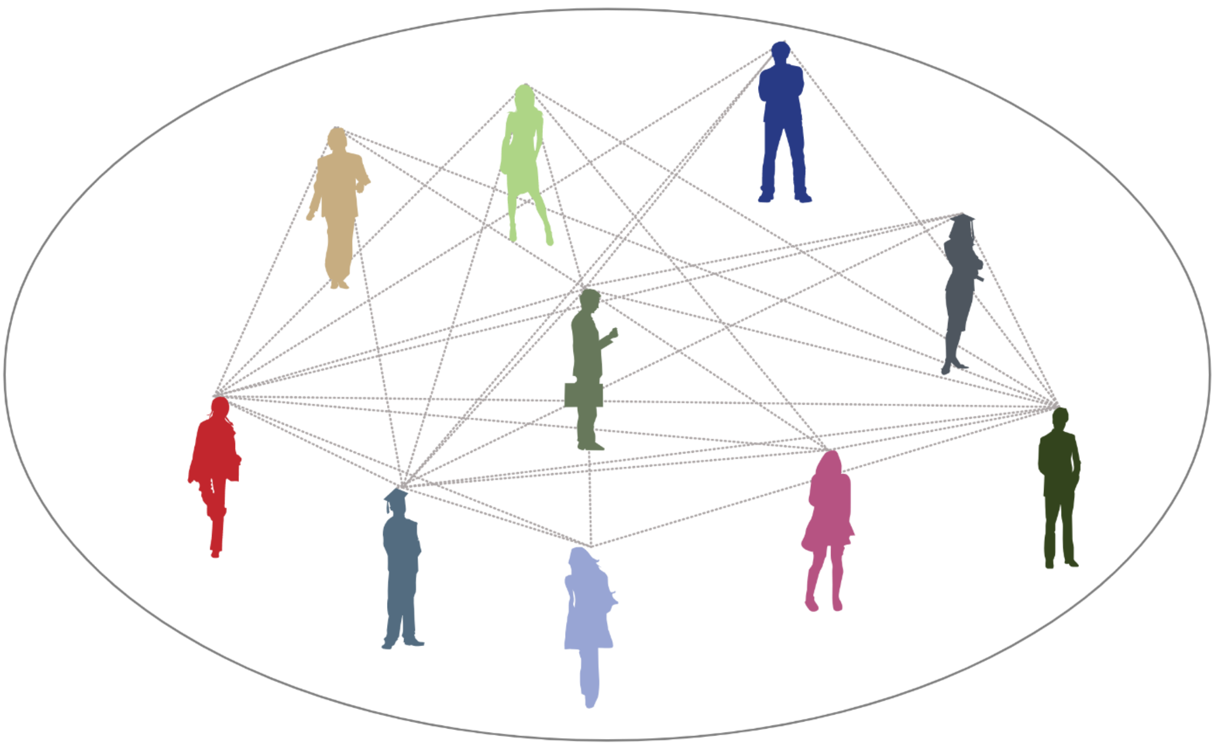

Figure 9: Collaborative culture within the MCC as described by ~40% of participants

It is worth noting that some instructors described the MCC as both a top-down and a collaborative hierarchy. This dissonance was not fully probed during the in-depth interviews, but the variability in members' perception of the MCC's internal structure may be influenced in part by how members came to be a part of the MCC. The initial cohort was essentially recruited by the PIs and were involved in activities such as writing the original grant and planning the formation of the community; the other two cohorts had higher rates of "stumbling upon" the MCC through conferences or during their search for a solution to a perceived need that the MDH CURE fulfilled. Some members of the later cohort entered the MCC after grant support had ended, which may have led to their initial perceptions of the community as unstructured. In addition, multiple members of the community had pre-existing networking relationships with at least one of the MCC PIs, while others had no such relationships prior to entering the MCC. It is possible that perceptions of the PIs as collaborating experts versus authoritative experts may be influenced by their method of exposure to and/or entry into the MCC (see Fig 11) or the characteristics of a pre-existing relationship with the PIs.

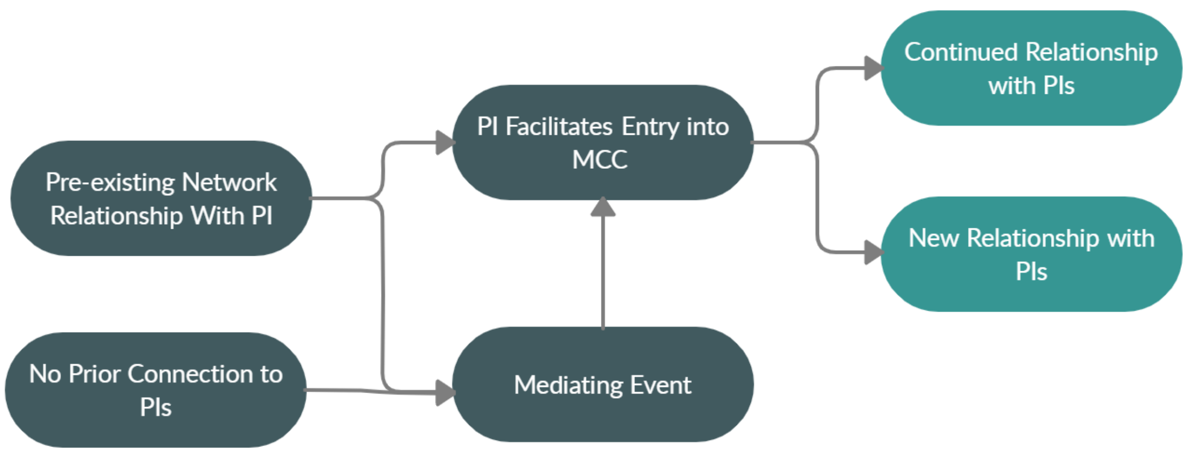

Figure 10: Pathways of MCC Participants' Entry into the MCC

<u>Conclusion 3: Leadership Within the MCC is Based on Contributions to the Community</u>

Which community members are perceived as leaders within the MCC is influenced by the level of contributions to the community through experience with MDH and/or teaching the MDH CURE and area of expertise. The peer leaders identified in interviews stood out to instructors because of their contributions to the community. Person MA was perceived as an innovator and expert in adapting the MDH CURE not only to community colleges (their institution classification), but also across course levels (such as into upper division level courses) and had very high collaborative activity. Person MA developed numerous teaching materials and made those easily available to the community. Although Person MA was perceived as "the" community college expert within the community, they were referenced as a resource used by all institution types. Person MB was perceived as a peer leader due to their unique area of expertise within the community. As a DBER expert, Person MB was the primary source of pedagogical analysis and reform. They were most referenced as an author on papers, but also for their contributions to the community at annual meetings.

Conclusion 4: MCC Member Have Overlapping Networks

Membership of a professional science society is not uncommon in postsecondary faculty. Science societies may be vested in the general field of science, such as the American Association for the Advancement of Science (AAAS) or discipline specific, such as the American Society for Biochemistry and Molecular Biology (ASBMB).

Science education is the source of future science professionals, and so discipline-specific societies dedicated to continual improvement of education within their discipline have become increasingly more common and are a driving force of DBER. But even those societies that are dedicated to the general discipline or the umbrella of science often form councils, committees, and hold activities intended to examine and address issues in STEM education. College science instructors represent the intersection of science and education, and professional societies facilitate the advancement of the discipline. So, it is unsurprising that many claim membership to professional societies and activities involved in science education improvement.

Professional societies represent networks external to the MCC. Just over half (53.8%) of the instructors interviewed discussed attending national meetings of professional meetings or activities, and a total of 63% of the interviewees discussed involvement with professional societies. Multiple government initiatives have attempted to facilitate the integration and collaboration of professional societies with academia, including the keystone report *Vision and Change in Undergraduate Biology Education* (American Association for the Advancement of Science, 2011).

Professional societies represent a social network of individuals exchanging information and collaborating to shape the culture and focus of the society, but they also shape the culture of a discipline (Wei et al., 2011). Seven of the 13 MCC instructors interviewed stated that they heard at least one of the PIs present on the MCC at a professional conference. Therefore, they are important potential platforms for the promotion and support of CUREs within biochemistry, biology, and chemistry.

Conclusion 5: The MCC Benefits from the Strength of Weak Ties

Individuals are most likely to form social connections to individuals who are both physically close and socially similar to them – in other words, individuals that require the least amount of effort (Rogers, 2003). Homogeny in groups can hinder performance and innovativeness (Hong & Page, 2004). An individual whose social network consists of highly similar individuals has less exposure to new information, as all the links in their social network are likely to have access to the same or similar information. The strength of weak ties theory posits that an individual forms weaker network links with individuals dissimilar from them, and yet, those dissimilar links are more likely to provide new information the individual may not otherwise be exposed to (Rogers, 2003).

Only two of the interviewed members of the MCC had a high level of CURE knowledge prior to joining the MCC. The majority (six instructors) had moderate knowledge, some (three instructors) had limited knowledge, and two had no knowledge of CUREs at all. Regarding CURE knowledge at the time of entry into the community, individuals in the MCC formed a moderately heterogenous network.

Several of the interviewed instructors had a pre-existing network relationship with at least one of the PIs, but only two worked directly with a PI as an undergraduate researcher. Instructors became involved with the MCC primarily through one of three pathways: a PI contacted them directly to participate in the MCC, they re-established contact with a PI after hearing them speak at a meeting, or they established a new relationship with a PI after exposure to the MCC through a presentation at a conference. In the latter cases, the relationship with a PI was a "weak tie" which provided new information by introducing participants to CUREs and/or the MCC.

Conclusion 6: The MCC Fulfills Most Needs and Local Colleagues Fill in the Gaps

Interviewed instructors in the MCC stated that the community met most of their needs when implementing and teaching the MDH CURE. However, when instructors encountered a need that was not fulfilled by the community, they most often turned to contacts in their other professional networks. Most instructors who utilized external resources turned to colleagues in their institution and a small minority turned to instructors at other institutions. These results seem to indicate that the heterogenous nature of the MCC helps sustain the community through providing diverse perspectives, experiences, and knowledge that is easily accessible by its members.

Conclusion 7: Face-to-Face Annual Meetings are Invaluable

Almost all interviewed instructors indicated the value of the MCC's annual meetings, particularly those which were held in person, rather than remotely. The meetings were used to establish new network ties and reinforce the strength of existing ties, which seem to correlate with a sense of integration and belonging to the community.

The Role of the Malate Dehydrogenase CURE Community in the Change Process

The innovation-decision process is a series of stages through which a potential adopter passes while deciding whether to adopt or reject an innovation. In this case, the MDH CURE is the innovation and the MCC is a social network attached to the innovation which promotes and supports its adoption. The innovation-decision begins with awareness of the innovation's existence, the formation of an opinion or attitude towards the innovation, the decision to adopt or reject the innovation, the experience of implementing the innovation, and finally, confirmation that the individual has made the correct choice in choosing to adopt or reject the innovation. Using Roger's

(2003) DOI as a theoretical framework, codes were arranged within themes that correspond to the stages of the innovation-decision process (see Figure 11).

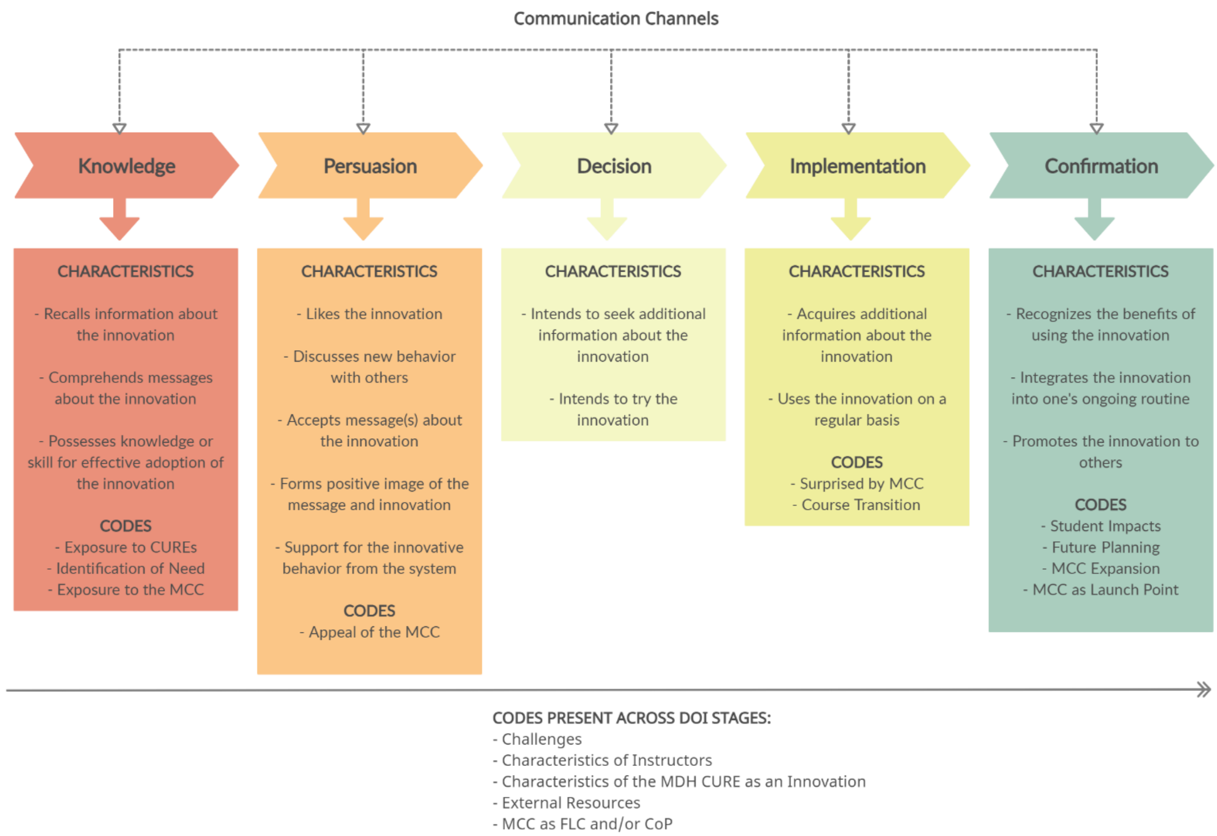

Figure 11: How codes relate to Rogers' DOI framework

<u>The Knowledge Stage</u>

In the knowledge stage, a potential adopter is exposed to an innovation. They may acquire one or a combination of three kinds of cognitive activity: awareness that the innovation exists, knowledge of how the innovation works, and/or understanding of why the innovation works (Rogers, 2003).

Conclusion 8: CUREs are Still in the Relatively Early Stages of Diffusion

Of the 13 instructors interviewed, only two indicated high levels of knowledge about CUREs prior to entering the MCC. Most instructors were aware of CUREs but did not have in-depth knowledge of them, and/or had not sought out additional information. A small minority had never heard of the term "CURE" and/or did not realize that there were alternatives to teaching traditional laboratory curricula.

The idea of incorporating authentic scientific research into undergraduate education is not a new one. However, the concept of a formalized curricula to do so in the classroom is a relatively recent development. The predominant curriculum being taught in most science laboratory courses is still the traditional, "cookbook"-style in which students follow a protocol to reach a predetermined result which is known to the instructor (Stains et al., 2018). Therefore, members of the MCC may be categorized as early adopters of CUREs, although their adopter category within the MCC may differ.

Conclusion 9: Awareness of CUREs Alone Is Not Incentivizing

Simply being aware of an innovation is not sufficient to incentivize potential adopters to implement the innovation; they must perceive a need or problem which the innovation solves (Rogers, 2003). Furthermore, Andrews and Lemons (2016) propose that dissatisfaction with the teaching experience or professional image are necessary for biology instructors to engage in pedagogical change. Nearly half of the MCC instructors interviewed cited dissatisfaction with the curriculum they were teaching prior to implementing the MDH CURE and joining the MCC. Four instructors described a change in their job role or position, including being hired at a new institution, as an opportunity to change their curriculum and begin teaching the CURE.

Conclusion 10: The MCC PIs are Highly Visible Change Agents

Most of the MCC instructors interviewed stated that they learned of the MCC through a presentation by a PI at a professional meeting or conference. Even when an instructor had a pre-existing tangential relationship with a PI, they were motivated through exposure at a presentation to reestablish contact with the PI and enter the MCC.

The Persuasion Stage

The persuasion stage of the innovation-decision process is highly affective. In this stage, the potential adopter begins to form an opinion or attitude toward the innovation; that opinion or attitude may be favorable or unfavorable (Rogers, 2003). In the persuasion stage, the potential adopter begins to engage in hypothetical scenarios in which they consider the role of the innovation in their individual context, and how the innovation will function as a solution to a perceived need or problem.

Conclusion 11: Most Instructors Viewed CUREs Favorably

Of those instructors who were aware of CUREs prior to exposure to the MCC, most had a favorable opinion of them. One instructor stated that they were “dying” to start teaching CUREs, indicating a highly favorable opinion of the innovation. Only one instructor stated that they had a negative attitude towards CUREs, and this was due to misconceptions about the feasibility of teaching a CURE at their institution given the institutional constraints the instructor was bound by.

The fact that many instructors viewed CUREs favorably is probably related to the fact that most the instructors interviewed had teaching philosophies that favored active, inquiry-based, and/or experiential learning pedagogies.

Conclusion 12: Community Support was a Major Incentive for Joining the MCC

Of the thirteen instructors interviewed, three quarters indicated that the community associated with the MDH CURE was an incentive for joining the MCC. While more than half of the instructors also indicated access to materials and funds provided by the MCC were an incentive, the community’s support seems to be the primary persuasive element for joining the community. Some instructors were the only members of their discipline at their institution and cited a longing for sense of community with other members of their discipline. Several of the instructors interviewed stated that they would not have adopted the MDH CURE if it had not had the potential support of an associated community.

Conclusion 13: The MCC Has a High Level of Relative Advantage

As CUREs have become more popular, instructors have the choice of several pre-developed CUREs. Two highly popular options are the Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) and the Genomics Education Partners (GEP). Like the MCC, both SEA-PHAGES and GEP provide extensive resources and support, as well as facilitating knowledge-exchange and research collaboration (Jordan et al., 2014; Lopatto et al., 2008). However, GEP and SEA-PHAGES are both genomics-based CUREs. For instructors teaching courses with protein student-learning outcomes, there is a lack of developed, network protein-centric CUREs (Bell et al., 2017). The MCC's protein-centric CUREs fulfill a need for instructors that teach biochemistry and molecular biology courses. Over half the MCC interviewees indicated that the MDH CURE filled a perceived need for protein-centric course objects while other existing developed and/or network CUREs failed to do so.

Conclusion 14: The MDH CUREs Can Be a Highly Complex Innovation

Complexity is one of the major factors that ultimately determines an innovation's rate of diffusion (Rogers, 2003). For instructors unfamiliar with malate dehydrogenases or protein mechanics, the MDH CUREs can be a highly complex innovation which requires assistance navigating. There is a veritable wealth of MDH information available to instructors, and MDH research first requires a substantial knowledge foundation. Some instructors found the amount of information necessary to conduct research overwhelming, and numerous instructors described the lack of centralized organizational structure of that information to be a major challenge. The community has identified the lack of easily accessed and navigable information repository and onboarding procedures as a weakness of the MCC and is taking steps to address this, per interviewees. In the meantime, the guidance, assistance, and modeling by individual community members to some extent mitigates the complexity of the innovation, thus increasing its rate of diffusion.

Conclusion 15: The MCC Lowers the "Activation Energy" for CURE Adoption

According to Roger's DOI, innovations with certain qualities will diffuse faster and have longer-lasting sustainability. Among those qualities are the innovation's compatibility with the potential adopter's individual circumstances, the relative advantage of the innovation over the other available alternatives, the innovation's low level of complexity, the ability for the potential adopter to observe the innovation while in use by earlier adopters, and the ability of the potential adopter to try out the innovation for themselves (Rogers, 2003).

That common barriers exist to the adoption of innovative curricula is well-established. Time, effort, cost, resources, potential institutional resistance, and high levels of uncertainty are all hurdles the potential adopter must navigate when choosing to overhaul a college class (Govindan et al., 2020; Rogers, 2003; Shortlidge et al., 2015). The interviewed instructors had already determined that the MDH CURE was compatible as a solution for their perceived needs. The funding for materials and equipment supplied by the original MCC grant mitigated much of the challenges presented by cost and resources for the interviewed instructors. The community provided access to moral support, subject matter experts, teaching materials, and lessons learned by the earliest adopters in the first cohort, further mitigating many of the perceived barriers to MDH CURE adoption.

Instructors perceived that the associated community would reduce much of the uncertainty presented by the hypothetical scenario of implementing the MDH CURE. The other community members were perceived as resources for knowledge and troubleshooting advice, as well as "lessons learned" through more experience teaching the CURE (aka observability). The availability of ready-made teaching materials and experts reduced the complexity of the MDH CURE. In addition to facilitating implementation, which may be considered a "trial run", of the MDH CURE, the MCC did not require long-term commitment from instructors considering adopting it. Some instructors reverted to adapted versions of their original curriculum when the COVID-19 pandemic broke out. Therefore, the potential benefits of teaching the MDH CURE (primarily student learning outcomes and scholarly product) mitigated the potential risks associated with its adoption. This is particularly true for the middle and later cohorts, since these instructors could observe the MDH CURE while in use by the earlier adopters in the initial cohort, as well as hear testimonials from those who had already taught it.

The Decision Stage

The decision stage is characterized by intention to seek additional information about the innovation and intention to try the innovation (Rogers, 2003). This stage of the innovation-decision process was not clearly elucidated in the instructors' statements, likely due to the retrospective nature of the in-depth interview. Elements of the preceding (persuasion) and proceeding (implementation) stages were clearly illustrated, and it is likely that these decision-stage activities were grouped with similar activities that took place in the persuasion and implementation stages.

The Implementation Stage

The implementation stage of the innovation-decision process is the point in which the innovation stops being a hypothetical concept and becomes a practical reality. As the innovation – in this case the MDH CURE – is put into use, the potential adopter's behavior changes to accommodate the innovation's integration into their life.

Conclusion 16: Early and Efficient Integration into the Community is Crucial

Nearly one quarter of the instructors interviewed described initially feeling a lack of sense of belonging in the community. The term "onboarding" was initially used by an interviewee and describes a concentrated community effort to integrate new members into the community through outreach by other members. Onboarding also involves providing a "roadmap" to help new members navigate the vast knowledge and resources available within the community, thus reducing the high levels of uncertainty and complexity associated with the MDH CURE. Ultimately, onboarding is necessary for the sustainability of the CURE and the community. This is an area that the community acknowledges is currently lacking, and that lack had significant impact for some instructors' sense of belonging and self-efficacy in teaching the CURE. In contrast, those instructors who reported high levels of integration and sense of belonging had high levels of satisfaction with and enthusiasm for the community and MDH CUREs.

Conclusion 17: The Moral Support Provided by the MCC is Crucial

The MCC provides both resources and moral support during implementation of the MDH CURE. Resources included knowledge, access to expertise, technical support and troubleshooting, teaching materials, supplies, equipment, protocols, et cetera. Accessing these resources was the most cited reason for engaging other community members by the instructors interviewed.

The second most cited reason for engaging other community members was moral support. Moral support was defined as an intangible resource with an emotional affect and was exhibited primarily as encouragement or reassurance for instructors who had high uncertainty in their self-efficacy while teaching the MDH CURE, which was an inherently uncertain activity. Moral support was provided through individual interactions in subnetworks that exist within the community, as well as at annual meetings and from the MCC PIs. All instructors reported a sense of belonging to the community. Even those instructors who initially felt a lack of integration into the community reported an increased sense of belonging after attending an annual meeting, which facilitated the development of network connections within the community and thus a source of moral support. Therefore, moral support is probably a key component of a network CURE, as it increases sense of belonging and self-efficacy as instructors are able to receive reassurance to help them navigate the uncertainty of teaching a new curriculum.

Conclusion 18: The MCC Facilitates Professional Growth in Both Science and Education

Over one-third of the instructors interviewed described a mentoring relationship or interaction with at least one other member of the community. Members of the initial cohort were more likely to be seen as mentors towards newer members, members with less teaching experience, and/or those with less MDH research experience. These relationships were particularly valuable for adapting the MDH to the instructors' individual institutional context.

Membership in the MCC promoted feelings of self-efficacy in members' teaching abilities. One of the common statements was that instructors felt uncertainty and doubt that they were teaching the MDH CUREs "the right way" or that they were somehow "shortchanging" their students. These fears were allayed by reassurance from more experienced instructors, usually in the first cohort, or the community's DBER expert, Person MA.

The MCC also provided ongoing workshops and opportunities for professional development in both teaching and MDH science. Instructors reported feeling more connected to the scientific community even as they felt that they were honing their skills as an educator. Instructors who identified primarily as research scientists who teach felt that being a part of the MCC benefited their instructional practices and helped combine their identities as both a researcher and an educator. Instructors who identified primarily as teachers reported the reinforcement of their identity as scientists. Both instructors who identified primarily as educators and as research scientists reported a sense of belonging to the community.

Instructors reported that their involvement with the MCC gave them a competitive edge in hiring and promotion. Multiple instructors described their involvement in MCC and teaching the MDH CURE was a beneficial part of their evaluations for tenure. Another instructor stated that talking about their involvement with the MCC and teaching the MDH CURE benefited them greatly during their interview at a new institution, leading to their employment there.

Conclusion 19: The MCC Reduces Uncertainty Associated with the MDH CURE

The innovation-decision is an uncertainty-reduction endeavor (Rogers, 2003). An innovation has a high level of uncertainty, with associated potential risks to the adopter. This is evident in the fact that uncertainty was the most prevalent challenge discussed by the interviewed instructors. The MCC helped instructors navigate that uncertainty by providing opportunities to view the MDH CURE – the innovation – in action during both the persuasion stage and the implementation stage. During implementation, instructors built on the lessons learned through the experience of the initial cohort and adapted accordingly. In some cases, this meant receiving reassurance that unanticipated effects, such as student resistance, was “normal”. In other cases, this meant not repeating mistakes made by previous cohorts during their implementation of the MDH CURE.

Some instructors had no experience with MDH or conducting protein research. More than 60% of the instructors reported a lack of familiarity with MDH as a major challenge as they began implementation of the CURE. However, the MCC bolstered instructors’ confidence by providing easily accessible experts and foundational knowledge. Most instructors felt reassured that if they encountered issues, the PIs or other members of the community would be able to assist them. Although there were exceptions to this – one quarter of interviewees stated they felt a lack of sense of belonging or initial integration into the community – for most instructors, the community largely mitigated most of the uncertainty associated with MDH and teaching the MDH CURE, as demonstrated by the codes Appeal of the MCC (the community associated with the MDH CURE), Engages the Community (accessing expertise, protocols, teaching materials), and External Resources (relatively few resources outside of the community were used).

Conclusion 20: MCC Instructors Face Diverse Challenges During Implementation

Almost all instructors reported challenges they faced while implementing and teaching the MDH CURE. Three quarters of the instructors interviewed reported feeling that teaching the CURE was “a lot of work”. Implementing the CURE seems to require a high level of cognitive effort as well as time.

Uncertainty was the most cited challenge faced by instructors. For some instructors, this uncertainty manifested due to their unique institutional context, which meant they were unable to find an experienced community member with a similar context to observe and benefit from the lessons learned during that member's implementation of the CURE. This factor may have contributed to instructors' feelings that the CURE was work-intensive. As instructors became more experienced by teaching the CURE through successive iterations, the amount of uncertainty was reduced.

Student perceptions of the CURE was perceived as a major challenge by more than one-third of the interviewed instructors. Student resistance to active-learning strategies is a well-documented phenomenon (Deslauriers et al., 2019; Downing et al., 2020; Seidel & Tanner, 2013; Tharayil et al., 2018). For most instructors, this was mitigated by the perceived benefits to students from participating in the CURE. Multiple instructors struggled with a lack of "student buy-in" to the CURE. For less experienced instructors or those who were concerned with tenure, negative student evaluations were a major concern.

Conclusion 21: The MDH CUREs are Highly Adaptable

Reinvention occurs when an innovation is modified by a user during implementation and adoption (Rogers, 2003). Reinvention is more likely to occur if certain qualities of the innovation are present: the innovation is complex or difficult to understand; the user does not have adequate understanding or knowledge of the innovation; the innovation is a general concept or tool with multiple applications; the innovation is implemented with the intent to solve a varied range of problems or needs; the innovation fosters a high level of local ownership; a change agent or agency influences its adopters to modify the innovation; the innovation must be adapted to the structure of the organization adopting it; or the innovation is in the later stages of widespread adoption and later adopters modify the innovation based on the experiences and insights of earlier adopters (Rogers, 2003). Several of these conditions apply to the MDH CURE and are therefore relevant when examining the role of the MCC in the change process that occurs when instructors adopt the MDH CURE.

The MCC is comprised of instructors teaching MDH-centric CUREs. The community's CUREs are inherently adaptable in that the community has developed multiple MDH CUREs and focuses on providing the CURE scaffolding for developing individual MDH projects at instructors' institutions (see Figure 2). In fact, the MCC website describes the options for creating an MDH CURE to suit the needs of any instructor as "nearly endless" (*Project Areas2 — MCC*, n.d.). The diversity of the initial cohort, and the community as a whole, provides a wealth of developed, observable CURE components fine-tuned through trial and error which new instructors can then use as a template to build their own CURE curriculum at their institution. The research topic – MDH isoforms and mutants – allows instructors to choose from a wide variety of topics the research focus of their CURE (see Table 11). All 13 instructors discussed the pedagogy of the CURE, their specific curriculum, or how they taught the CURE. Over one-third of instructors described ways in which they intended to further "tweak" their MDH CURE curriculum to make it better suited to the needs of their students and/or their institutional context.

Table 11: Current and Future MCC Faculty MDH Projects

Ongoing Projects	Future (Pending) Projects
Specificity and Catalysis Allosteric Regulation Plant MDH: Isoforms and Photosynthesis Drug Design Impact of Phosphorylation/Post Translational Modification Protein-Protein Interactions ad Metabolon	Folding and Assembly of Structure of MDH Extremophile and Structural Adaption Evolution of MDH

Table 11: MCC Faculty MDH Projects. Adapted from *Project Areas2 -- MCC* (n.d.). Copyright MDH CUREs Community.

Conclusion 22: MCC Members Showed Resiliency Through the COVID-19 Pandemic

COVID-19 was a massive disruption for almost every aspect of academia. Many college educators found themselves scrambling to modify their curriculum for remote instruction with relatively little advance warning, an especially daunting task for courses based in experiential learning. For MCC members, however, the community provided resources and support to navigate the challenges associated with teaching a biochemistry lab during the pandemic. The community PIs provided a workshop on how to conduct MDH bioinformatics projects and transition the MDH CUREs online. Community members assisted one another with resources and guidance for the change to remote learning. Most instructors continued to teach the MDH CURE during the pandemic, and those who did not resumed their MDH CURE once the pandemic ended. Thus, the community facilitated instructional resiliency in its members.

For some members, the community provided crucial moral support during the pandemic. One instructor described feeling a sense of belonging when they attended an annual meeting and discussed with other members the challenges of adapting the CURE and teaching remotely while caring for young children who were attending school remotely and providing high levels of emotional labor. The community provided safe space for instructors to seek moral support for teaching the MDH CURE, but also for issues not directly related to teaching or the CURE. Such social support systems are crucial for individual resiliency (Ozbay et al., 2007).

<u>The Confirmation Stage</u>

In the confirmation stage, the individual seeks reassurance that they have made the correct decision regarding the adoption or rejection of the innovation (Rogers, 2003). Successful adoption occurs when the adopter benefits from using the innovation and recognizes those benefits. They continue to use and further integrate the innovation into their routine and begin to promote the innovation to others.

If the individual receives messaging or perceives that they have made the incorrect choice, they experience cognitive dissonance. They may also experience cognitive dissonance due to unmet expectations, misconceptions, or unanticipated consequences associated with the innovation. Cognitive dissonance is an uncomfortable emotional and mental state which humans seek to avoid or reduce if unavoidable. The individual may reduce or eliminate cognitive dissonance by changing their knowledge, attitude, or behavior (Rogers, 2003). If the innovation-decision led to the decision to adopt, the adopter may choose to discontinue use of the innovation to reduce cognitive dissonance. If an individual chose to reject the innovation, they may return to the decision stage and choose to implement the innovation. Later adopters are more likely to discontinue use of an innovation than those who adopt early (Rogers, 2003).

Conclusion 23: Instructors' Expectations and Experiences Don't Always Align

An innovation represents uncertainty for potential users, who form attitudes and expectations towards the innovation before, during, and after adoption. Initially, the potential adopter's attitude and expectations are shaped by messaging about the innovation which causes them to engage in hypothetical scenario-building. After adoption, the adopter's attitude and expectations are influenced by their experiences with the innovation, which may include unanticipated events or consequences. Thus, attitudes and expectations during the confirmation stage may be different from those formed during the earlier stages of the innovation-decision process.

Most instructors described aspects of the MCC and/or MDH CURE which surprised them. Some of these unexpected aspects were positive, and others were negative. In several cases, instructors reported conflicting "surprises". Multiple instructors described being pleasantly surprised by how collaborative and "egalitarian" the community was. Others described the community as a "silent world" with sporadic and disorganized communication that made them feel as if they were “thrown into the deep end of the pool” to implement the MDH CURE on their own without support.

Nearly half of instructors described misconceptions they had about the community. Several instructors reported expecting a research consortium, in which instructors exchanged knowledge about their ongoing experiments in an organized and communal fashion, but instead found that project silos existed within the community and instructors worked relatively independently unless they needed assistance, and the onus was then on the struggling instructor to reach out to the community. Multiple instructors expected that members of the community other than the PIs would reach out to new members and facilitate their integration into the greater community, but instead felt that there was “radio silence” and general confusion about what resources were available. Some instructors were uncertain what expectations or obligations the community placed on new members. Some members were initially unaware prior to the persuasion stage of the resources available through the MCC. Others were unaware of the resources available until after they had fully implemented the CURE and taught it for multiple iterations.

Conclusion 24: Despite Challenges, the MCC Serves Instructors’ Intended Purposes

Innovations are adopted because the adopter expects that the innovation will fulfill a need or solve a problem they are facing. While some interviewees described unfulfilled expectations for or misconceptions about the MCC, none indicated that the MDH CUREs and/or MCC had failed to fulfill the original need which motivated them to adopt it. Some instructors experienced challenges with the community itself, or while teaching the MDH CURE, yet all indicated that they continued or intended to continue teaching the MDH CUREs and being a member of the community. Even those instructors who were concerned about student perceptions and resistance praised the community and the CURE they taught.

Conclusion 25: The MCC Inspires Sense of Belonging and Loyalty to the Community

A sense of belonging to a community has major implications for psychological health and performance (Hagerty et al., 1996). Sense of belonging was discussed in all interviewed MCC members. Some members felt an immediate sense of belonging, while in others it was somewhat delayed, but in none was it completely absent. There appears to be a connection between sense of belonging and confidence and/or self-efficacy in these instructors. This was demonstrated by the sense of belonging, confidence, engages the MCC, and surprised by the MCC codes. All 13 interviews discussed beneficial aspects of their involvement with the community and/or teaching the MDH CURE. Instructors perceived that both they and their students received these benefits.

Conclusion 26: Teaching the MDH CURE Instills the Confidence to Teach Other CUREs

All interviewed instructors discussed new network connections and/or projects initiated because of their membership in the MCC. For many of these instructors, those new networks and projects overlapped in the form of a new non-MDH CURE designed with a colleague at their institution for incorporation into other courses to achieve the desired student learning outcomes in those classes. Others described reinforcement of network connections made within the MCC around MDH-based projects.

Many instructors discussed increased confidence and self-efficacy in their ability to teach CUREs. Some expressed interest in teaching other, non-MDH CUREs. Several described excitements to design a CURE based on their own non-MDH research projects. It seems that teaching one CURE increases the likelihood that an instructor will teach another, likely due to the uncertainty reducing nature of experience.

Conclusion 27: The MCC Has Reached Critical Mass

Critical mass of an innovation occurs when an innovation “takes off” because sufficient individuals within a system have adopted the innovation that its continued rate of adoption is self-sustaining. The MCC has reached critical mass, as evidenced by the MCC exposure, MCC expansion, and MCC as launch point codes.

Members of the middle and later cohorts discovered the MCC through a mixture of promotion by PIs or other members, and discovery in their search for a solution to their perceived need or problem that the community fulfilled. “Word of mouth” is an extremely persuasive method of promoting an innovation, as testimonials from members of an individual’s network are more powerful than empirical evidence of the innovation’s benefits (Andrews & Lemons, 2015).

All 13 members of the MCC discussed promotion of the CURE and/or MCC to others. Most discussions of the CURE or community happened between an MCC member and colleagues at their institution. Reception of the instructors’ messaging about the MCC were mixed, as several of the interviewed instructors were the only members of their discipline at their institution and the MCC’s CUREs are MDH-specific, which may not translate well into non-biochemistry or non-molecular biology courses. There appears to be specific resistance to CUREs, or at least the MCC, among interviewees’ chemistry colleagues.

Some instructors received significant pushback from colleagues against the implementation of an MDH CURE at their institution, or to their efforts to recruit colleagues into the community. Yet others described heightened interest and enthusiasm for CUREs from their colleagues after observing the implementation of the MDH CURE, even if that enthusiasm was for non-MDH CUREs. Several instructors recruited colleagues into the community. Many instructors discussed expanding the MDH CURE from the original course in which it was implemented into more courses within their department, or even other departments. Some members collaborated with colleagues to incorporate other courses into the member’s research project; in one example, a molecular biology course began producing the MDH mutants for analysis in the biochemistry course the MDH CURE was initially implemented in.

Interviewed instructors described discussing the MCC with friends, colleagues, and at professional meetings outside of the community. The MCC and its subsequent spin-off grants have generated critical mass.

> "So obviously we have this new grant that's up and coming, and I've been recruiting people … so I've been recruiting people and then when I would go to meetings, I've presented I think 2 posters about the MCC? So yeah, I was always talking to people either at meetings or just local colleagues or friends who, you know, from graduate school, and you know most all of them when I would tell them about it would be like "Oh I want to be a part of that, you know, that sounds pretty fun" so yeah, I definitely was promoting it as much as I could." – PUI Instructor

Conclusion 28: The MCC Influences Instructors' Identities and Self-Efficacy

Communities of practice are associated with identity and self-efficacy (Polizzi et al., 2021; Wegner, 1999). For instructors with research-intensive backgrounds, the MCC presented a way to connect with other science educators and pedagogical professional development, thus reinforcing their teaching self-efficacy and identity as a scientist who teaches science. For instructors with teaching-intensive backgrounds, the MCC provided avenues to reconnect with the scientific community and reinforced their identity as a teaching scientist. This is especially important for instructors who are isolated as the only member of their discipline at their institution, or institutions like community colleges that often place less emphasis or provide less support for science research activities.

CHAPTER 5

DISCUSSION

Implications and Recommendations

CUREs are still a relatively young pedagogy, and therefore have high levels of associated uncertainty. Only a few MCC members had high levels of CURE knowledge; most were aware CUREs existed but did not have extensive knowledge of or experience with them, and some instructors had never heard of CUREs or considered integrating authentic research into their laboratory courses. Most interviewees learned of the MCC and acquired greater knowledge of CUREs through direct recruitment by an MCC PI or through promotion of the CURE by a PI at a professional conference or meeting. Most of these instructors had pre-existing positive attitudes towards active-learning and inquiry-based teaching strategies which may have predisposed them to a greater likelihood of seeking out professional development and networking opportunities, but unlike other studies, such as DeChenne-Peters & Scheuermann (2020), none mentioned peer-reviewed publications as a source of CURE knowledge. Based on these interviews, change agents should actively promote CURE awareness through professional societies, conferences or meetings, and targeted seminars.

Awareness of the existence of CUREs is not in itself incentivizing. Instructors must see a need that the CURE can fulfill. For MCC members, the most common need was dissatisfaction with their current curriculum. This supports the hypothesis by Andrews and Lemons (2015) that instructional change requires prior dissatisfaction with an individual’s teaching. Based on the data from the MCC, this means that most early adopters for a CURE community will be instructors who are already dissatisfied with their current curriculum, already prefer active-learning strategies, and are actively seeking to change their curriculum. As a CURE community reaches critical mass, recruiting methods should shift to become more persuasive to overcome institutional inertia or instructor resistance due to perceived barriers. The most common barriers to CURE adoption are time, resources, and effort (Brownell & Tanner, 2012; Govindan et al., 2020; Shadle et al., 2017). Together, these are dimensions of the complexity of CUREs as an innovation and the associated uncertainty. Reducing complexity through structured onboarding, ease of access to experts and resources, moral support, observability of the MDH CURE in action at institutions with similar context, and sustained support throughout implementation will remove many of these barriers. Social learning theories – and specifically Roger's DOI – agree that interpersonal communication channels are more persuasive than merely presenting empirical evidence of an innovation's benefits (Andrews & Lemons, 2015; Rogers, 2003; Wegner, 1999). After critical mass has been reached, change agents should focus on recruiting through opinion leaders in networks that overlap with the CURE community, providing testimonials from more recent adopters, and showcasing strategies to reduce the uncertainty and complexity of the MDH CURE.

Another potential avenue of persuading instructors to teach CUREs is capitalizing on instructors' identities. MCC members described growth both as scientists and as science educators, regardless of their background experiences. Individuals with growth mindsets may be persuaded to teach a CURE and/or join a CURE community by offering professional development opportunities and mentoring relationships within the community that target both research and pedagogy. Faculty professional development cannot be a one-size-fits-all endeavor; instructor experience varies widely, and individuals enter STEM education with differing desired student learning outcomes, motivations for teaching, and strategies for achieving their goals in the classroom (Zagallo et al., 2019). Community college instructors often have less access to professional development opportunities than their peers at primarily undergraduate or research-intensive institutions (Hardré, 2012). Rural, low-income, and minority-serving institutions often have high rates of inexperienced instructors. While this trend varies by region, institutions large minority or low socioeconomic populations have more science instructors with less than 3 years of experience; this is especially true in the southern and western regions of the U.S. (National Science Board, 2022). By functioning as both a CURE FLC and an MDH CoP, the MCC provides professional development for members both as STEM instructors and as practicing scientists. This is consistent with literature that shows that involvement in an FLC influences self-efficacy and sense of identity as an instructor, while involvement in a STEM CoP influences self-efficacy and sense of identity as a scientist or researcher (Weinberg et al., 2021). The MCC instructors interviewed had mixed identity responses based on their background, training, and current institution. Some identified primarily as researchers who teach, while others identified primarily as educators who conduct research, but participants from both categories described increased knowledge, skills, and confidence in their secondary identity. Instructors with research-intensive training and backgrounds felt more confident teaching science, and instructors with teaching-intensive training and backgrounds felt more confident conducting science. Membership in a CURE community such as the MCC also provides professional networking at a national level to instructors who may otherwise be isolated through geography, a lack of colleagues in their field at their institution, or low levels of financial support. Instructors have access to workshops, resources, expertise, and mentoring. Involvement with a supportive CURE community not only facilitates achieving desired student learning outcomes by supporting implementation and sustained adoption of a CURE, but also provides a form of continuing professional development and relevancy for instructors at all levels – but especially those who are still novice educators.

Most MCC members had an existing relationship with at least one of the MCC PIs. All three PIs are experienced biochemists regarded as experts in MDH and have well established professional networks. When designing a CURE community for sustained CURE adoption, subject matter experts are critical, but change agents should also seek out those with wide-reaching network connections that span across disciplines, geography, and institutions. The initial MCC cohort consisted largely of individuals recruited by the PIs. If the MCC PIs are the central nervous system of the community, then the initial cohort is its backbone. Initial cohorts should be planned to incorporate individuals who are opinion leaders within their discipline and/or at their institutions, and those individuals should be highly diverse as heterogenous groups have higher performance across several dimensions (Hong & Page, 2004).

Successive cohorts should also be planned for heterogeny, although the nature of innovation diffusion after early adopters is less controllable by change agents. The diversity of the community will provide a larger range of resources for community members to rely on during implementation and inoculate against discontinuance of the CURE as the community will fulfill most of their needs. At the same time, diversity of members means that the community will capitalize on the strength of weak ties both in recruiting and in the growth of the community. Strong network connections are made between more similar individuals, and therefore are less innovative. Dissimilar individuals are more likely to have weaker ties but provide more new information or ideas to both parties that homogenous connections would not. Therefore, diversity in each successive cohort will ensure the community continues to expand and does not stagnate. At least one peer leader in the MCC was perceived as a leader because of the nicheness of their expertise within the community.

The MCC itself is both a community of practice and a faculty learning community. The community was originally designed to address multiple needs within the science education community, including the inconsistent use of evidence-based, experiential science instructional practices and a lack of robust developed protein-centric CUREs. Together, the community has developed, promoted, and sustained the use of pedagogically effective MDH CUREs. As both a CoP centered around fundamental MDH research and an FLC centered around effective experiential student learning, the MCC has been successful in achieving many of its members' objectives.

Within the community there exist subnetworks formed on pre-existing network connections, discipline/expertise, research interests, teaching objectives, institutional context, and physical proximity. The ways in which the community is perceived by its members varies depending on individual instructors' experiences. When developing a CoP/FLC-supported CURE, designers should carefully consider the nature of leadership, networks, and collaboration they wish to see occurring within the community. Building a network using cliques facilitates the rapid building of an early user base, but ultimately hinders rapid diffusion efforts (Choi et al., 2010). Therefore, it is important that new members' integration into the community be actively facilitated. The lack of structured onboarding within the MCC at the time of the in-depth interviews was described as a source of frustration and uncertainty for instructors who joined outside of the initial cohort. A structured entry into the community can shape the nature of the instructors' experience, sense of belonging, perceptions of the community, and expectations of the community and CUREs. Misconceptions about the role of the community or the CURE it is formed around can negatively impact an instructor's experience and increases the likelihood of rejection of the CURE or discontinuance after implementation. This is especially true as the community reaches critical mass and acquires more later adopters, who are more likely to discontinue use of an innovation than earlier adopters. Those instructors who initially perceived the MCC as unstructured may have felt an acute lack of integration due to perceiving the rest of the community as "tight-knit" due to the existence of pre-existing connections. Thus, onboarding to facilitate early and effective integration into the community is crucial. Ultimately, structured entry or "onboarding" into the community is a key element for shaping the culture of the community going forward.

Activities that make members highly visible to one another within the community are a crucial element of a CURE community. MCC members described project silos, or the lack of visibility regarding other instructors' research projects, as a challenge within the community. Inversely, they described the annual MCC meetings as highly beneficial due to the opportunity to exchange information across the community, and forge new network connections. The professional development workshops, particularly those during the COVID-19 pandemic, were also highly valuable to instructors. Therefore, community designers should plan regular, organized activities that promote community-building, research collaboration, idea exchange, and professional development. A strong sense of belonging to the community fosters instructor resiliency against local disruptions such as institutional resistance, and national disruptions such as the COVID-19 pandemic. The moral support and resources provided by the MCC served as inoculation against discontinuance during the COVID-19 pandemic for the majority of MCC instructors.

Peer leadership within the MCC was largely shaped by the contributions made to the community by these perceived leaders. Persons MA and MB were the most referred to MCC members besides the PIs who were identified as leaders. Person MA was The Community College Innovator; they belonged to a community college, developed many teaching materials adapting the MDH CURE across course levels and made those materials widely available to the community, and were highly active in the community as a mentor and collaborator. Several members stated that they would not have joined the MCC or taught the MDH CURE if it had not been for the support and services provided by Person MA. Person MB was The DBER Expert; they had a niche expertise in education research and effective pedagogy that was crucial for instructors trying to untangle the data of student outcomes from the CURE. Several interviewees stated that Person MB was a key player in the community's success and wished that Person MB had been present from the formation of the community. Therefore, CURE community developers should consider implementing certain roles in their initial community cohort: an innovative designer of teaching materials that scale across institution types and course levels, and a DBER expert to help guide CURE development using data-driven strategies.

Future Directions

Utilizing the wrong communication channel, or even the right communication channel at the wrong time, can hinder innovation diffusion efforts (Rogers, 2003). Thus, it is important to understand which communication channels are important and when they are most utilized or valued by the potential adopter. Instructor peer networks represent communication channels that underly each stage of the innovation-decision. The role of communication channels external to the CURE community should be more closely examined to characterize their influence on the CURE's diffusion. This will allow change agents to focus their efforts on the appropriate networks at the appropriate times.

Instructors' perceptions of the MCC are likely influenced by numerous factors. The influence of these factors and their interactions should be further elucidated to better understand the unique needs and experiences of individual instructors who wish to adopt a network CURE with an associated community such as the MCC. The effects of factors such as sex/gender identity, institutional context, area of expertise, department size, research and teaching experience, and various aspects of instructors' identities were not fully explored by this study. This study does serve, however, to provide a foundation on which to build for future CURE diffusion efforts.

This study did not probe deeply into the internal structure of working groups within the community, although these were mentioned in interviews. Studies utilizing social network analysis may be better suited to elucidating the intricacies of interpersonal interactions within CURE communities, however this was not deemed feasible within the time allotted for a master's degree thesis.

Limitations of This Study

To the best of the author's knowledge, this is the first study to examine the role of a CURE community throughout each stage of Rogers' (2003) innovation-decision process. The MCC is a community of practice centered around teaching malate dehydrogenase CUREs. As such, this specific community may be of little to no interest to instructors who feel that it is irrelevant to their research or the courses they are teaching. Therefore, some results of this study may not be broadly applicable to all CUREs or CURE communities. Two new grants have been launched out of the original MCC1.0 grant which facilitate the development of CURE communities and new CUREs by instructors tailored to their own research interests, not just MDH- or protein-centric CUREs. These grants and similar initiatives represent an opportunity to explore more broadly relevant aspects of CURE communities and the interactions happening within them.

Another consideration for the application of these findings is the study's sample. The sample size is small (n=13) and likely suffers from selection bias: the majority of MCC members who responded to interview requests were those with high enthusiasm for and/or involvement in the community. Therefore, although the dataset is highly rich and does showcase the experiences of at least some later adopters, these findings are likely not broadly generalizable to all CURE communities. Nor may the recommendations be applicable to instructors who have fixed mindsets or who are comfortable in their current career trajectory.

Furthermore, the PI of this study is a novice interviewer. It is likely that the interviewer's inexperience conducting in-depth interviews introduced some level of inconsistency across interviews, which may have influenced participants' responses and therefore these findings. For example, in some interviews, the terminology "appeal of the MCC" was used versus "expectations of the MCC". In some instances, it was unclear whether participants were discussing the CURE community itself or the MDH CURE, and the interviewer failed to seek sufficient clarification. The impact is expected to be minimal, as the innovation (the MDH CURE) and the change agent (the MCC and the MCC PIs) are often inextricably intertwined in the minds of potential adopters. However, there is a distinct opportunity to further untangle the role of the innovation (the CURE) from that of the CURE community.

Regarding peer leaders, not all interviewees were comfortable identifying by name other members of the community. Others declined to fully elaborate on their interactions with those perceived leaders within the community. Although the anonymous nature of the interviews and rigor with which participants' identity would be protected was fully disclosed to interview participants, some expressed discomfort that the community may perceive their comments in a negative light, and thus may not have been as candid in their interviews as they might otherwise have been.

This study was conducted retroactively, after the initial MCC grant had ended. Additionally, many members of the original MCC grant (including several interviewees) were also involved with the “new” grants and projects sparked from it. Interview participants may have experienced some level conflation during their interviews between the “original” MCC grant and the “new” grants that also involve members of the MCC.

Despite these limitations, this study provides a solid foundation for future CURE diffusion research regarding community-supported network CUREs.

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APPENDIX

IN-DEPTH INTERVIEW GUIDE

MCC Semi-Structured Interview Protocol

Directions for Interviewer

The questions to be asked of the interviewee are numbered. Lettered items are sub-objectives that may be asked of the interviewee if the interviewee does not discuss them in their answer to the original question. Interviewees may answer multiple questions in response to another question prompt.

Introduction

1. What is your name and title?
2. What is your current position, department, and institution?
3. What is your expertise and research background?
4. What is your teaching experience, including previous institutions?
5. What is your teaching philosophy?
6. Prior to participating in the MCC, what was your level of knowledge or experience with CUREs?

Introduction to the MCC

1. How did you learn of the MCC?
2. What were your initial expectations for the MCC?
3. How did you first start communicating with others in the MCC?

MCC Structure and Utilization

1. What did you use the MCC for?

2. How did you maintain or sustain contact with others in the MCC?
3. Besides the PI's and grant administrators, who were the peer leaders that emerged within the MCC?
4. When in the change process – researching, implementing, re-inventing the MDH CURE- did you rely most heavily on the MCC?
5. When in the change process – researching, implementing, re-inventing the MDH CURE – did you rely on the MCC the least?
6. How did the role of the MCC change over time?
7. What do you feel was missing from the MCC?

<u>Utilization of Internal (MCC) vs External (non-MCC) Resources</u>

1. Where else did you turn to outside of the MCC to get help with teaching the CURE?
2. Who did you talk to about the MCC itself?
   a. Within the MCC?
   b. Outside the MCC?

<u>Impacts of the MCC</u>

1. How did the MCC affect your teaching experience?
   a. … of the MDH CURE?
   b. … outside the MDH CURE?

2. Beyond teaching the MDH CURE, what impact did participation in the MCC have on you or your department?

3. Did participation in the MCC facilitate any new communication networks or projects for you? (Such as "sparking" conversations with colleagues at conferences, discussions/collaboration with peers within or external to department, institution)