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# Bulldozing the STEM Silos in Omaha: While Engaging P-12 Teachers and Building Campus STEM Excellence

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AAAS Arise Blog:

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It has been said that all universities "do STEM these days", but what exactly does it take to "do STEM" well? Questions commonly heard on a university campus these days include: "What is the STEM context for inquiry?", "Should P-16 STEM be a campus priority?", "How can a campus break down departmental silos for interdisciplinary workforce development?" In many ways STEM represents, at its core, an interdisciplinary approach and workforce development context to learning, that rigorously engages the core concepts of science, technology, engineering, and mathematics (Tsupros, N., Kohler, R. and Hallinen, J., 2009; National Science and Technology Council, 2018). Additionally, STEM concepts are found in most any P-16 curriculum (to include reading, writing, philosophy, history, etc.). How does it all come together for a campus trajectory toward STEM excellence? These questions, as well as projected workforce needs, put "STEM" as an important conversation on most campuses these days, and it certainly is the case on our campus, at the University of Nebraska at Omaha (UNO). Further, it is a truly a national dialogue, as educational institutions strive to more effectively work across disciplinary lines for "convergence", where the insights and approaches from different disciplines can come together for finding creative solutions for our most difficult societal problems (National Research Council, 2014). Convergence is also a growing theme for innovations in P-12 STEM teacher training, such as at the National Science Foundation's 2018

Noyce Teacher Scholarship Summit (http://www.nsfnoyce.org) and also across scientific programs as one of NSF's 10 big ideas (https://www.nsf.gov/news/special_reports/big_ideas/).

At UNO, based in the heart of Omaha, Nebraska, we typically define ourselves as a "Metropolitan University," which in its simplest terms, is an institution that accepts all of higher education's traditional values in teaching, research, and service, but takes upon itself the additional responsibility of providing engaged leadership within the metropolitan region. The overall goal is certainly one of convergence, in our efforts to leverage human and financial resources of the university as full partners to improve the region's quality of life. Thus, for STEM at UNO, it is truly a P-16 endeavor for our 15,431 students and our metropolitan community, and one that welcomes P-12 teachers as colleagues within our STEM reform efforts.

First and foremost, at UNO, STEM is about working collaboratively across disciplinary lines to make real differences in how P-16 students learn in all disciplines and to find insights across disciplines. At the same time, we know that deep dives into STEM disciplines will help propel students into their productive individual careers as thoughtful and convergent problem solvers. Such university-wide collaboration across and within STEM areas is both complex and challenging though, and so where does a university focus? What footholds for quality collaboration are available to try to break down historical silos? At the University of Nebraska at Omaha, we have found that developing comprehensive programs that collectively support high quality P-12 teachers can be a strong catalyst to wider STEM excellence and the convergence across disciplines, which can also make a difference for all students (whether they be pre-service teachers, in-service teachers advancing their education, traditional STEM majors and non-STEM majors). Moreover, we've increasingly observed noticeable impacts across STEM programs into the wider metropolitan community, such as industry and school districts.

Investing in P-12 teachers is critically important in STEM workforce development (Carmichael, 2017). In today's highly technical economy, the need for high quality STEM teachers has never been greater (Moritz, 2018). There is a growing need for deep content knowledge for teachers, while synergistically emphasizing inquiry-based pedagogy skills that can be deployed once in their own classrooms (Bybee, 2013; Kelley & Knowles, 2016; Slavit, Nelson, Lesseig, 2016). These practices allow students to learn technology-related tools as well as the contextual expertise of business and industry in a practical and engaging way. However, many universities still struggle to encourage faculty to disseminate knowledge in a convergent and inquiry-based, student-focused way. Therefore, many teachers -- in both K-12 and higher education -- continue to "teach as they were taught." In our UNO programs, we've put considerable emphasis on "practicing what we preach" by changing the way we present material in and out of the university classroom, and often involving P-12 teachers in various UNO STEM initiatives. As we like to describe it at UNO, "we've taken a bulldozer to the cement silos of STEM" to provide the interdisciplinary opportunity for collaborative work. This collaborative work across UNO, Omaha, and Nebraska is increasingly gaining recognition, such as in a 2016 Community-University Engagement Award by the Association of Public and Land Grant Universities, a 2017 recognition of Omaha and Nebraska by STEM Ready America (See: http://stemreadyamerica.org/article-nebraska-way/) and even in a late 2018 report sponsored by ACUMEN and associated with online STEM tutoring that referenced Omaha as surprisingly

leading the nation (See: https://www.ozy.com/acumen/the-next-generation-of-stem-leaders-hails-from-nebraska/91012).

A closer look at some of our silo bulldozing collaborations at UNO will illustrate how we are increasingly trying to break down the departmental barriers present on a university campus and in our wider Omaha metropolitan community.

> Cross-Department Collaboration to Combat Computer Science Teacher Shortages:
> Various graduate courses and programs for teachers at UNO are interdisciplinary in order to provide particularly content rich. For example, the Department of Computer Science and Teacher Education now has one of the first Master's Degree programs in Computer Science Education (https://www.unomaha.edu/college-of-information-science-and-technology/computer-science-education/graduate/ms-csed.php). This degree program, which is offered jointly by the College of Information, Science and Technology, and the College of Education, entails coursework from both colleges and results not only in a M.S. from the Computer Science Department, but also results in a Nebraska Supplemental Teaching Endorsement from the College of Education for Instructional Technology that is CS focused. The MS program has become widely popular in the metropolitan Omaha area in just four years, with 35 teachers now in the program and our first graduate in December of 2018. Further, the program is available to individuals with educational interests outside of schools, such as corporate trainers, informal educators (such as staff at museums), and instructors at community colleges. A private foundation is contributing partial tuition assistance for selected teachers from high-need and rural schools. This focused development of computer science teachers has been shown to help to address a particularly critical shortage of computer science teachers that has many inherent challenges with teacher training and certification pathways (Code.org, 2017; Thompson, 2018; Foresman, 2018).
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> STEM Content-Rich Graduate Programs for P-12 Teachers:
> Other more established UNO graduate programs, such as a Masters of Arts for Teachers of Mathematics in the Math Department (See: https://www.unomaha.edu/college-of-arts-and-sciences/mathematics/academics/graduate-mat.php) and the STEM-related Secondary Graduate Programs in the Department of Teacher Education (See: https://www.unomaha.edu/college-of-education/teacher-education/graduate/secondary-education.php) allow teachers to integrate large numbers of STEM content rich courses that are also strong in inquiry-based pedagogies. Innovative content-rich courses have been recommended to universities as a national strategy for supporting high quality STEM teaching and building P-12 pathways to 2-year and 4-year institutions (National Science and Technology Council, 2018; National Academies of Sciences, Engineering, and Medicine, 2016). Further, a graduate STEM education course, called Data Driven Decision Making for Educators is also available (and typically required) across all the campus STEM graduate programs, to help all teachers regardless of STEM disciplines to better use and interpret educational data for enhanced student learning. Many of the concepts taught relate to wider data use, such as variance, error in measurement, assessment validity, logic modeling, and other concepts that cross STEM disciplines at large, but are also particularly important for interpreting educational impacts at the

classroom and school levels so critical for today's teachers (Zacharoula P., Anastasios A., 2014).

Teacher-Researcher Partnerships: Another example that engages and enhances practicing teachers, is our Teacher-Researcher Partnership Program (TRPP) (see https://www.unomaha.edu/college-of-arts-and-sciences/teacher-researcher-partnership-program/index.php) where we mentor current teachers in genuine research practices, centered around integrating teachers in field-based research underway by selected STEM faculty at UNO. These methods of training follow high impact practice recommendations (Kuh, 2008; American Association for the Advancement of Science, 2011) and provide a strong foundation in science content, practices, and processes for the participants. As a by-product, faculty across STEM disciplines and across educational levels come together to implement the programs and disseminate the results. Since science teachers in the public schools often lack opportunities to actually do science investigations (Mansour, 2009), this program, covering a six-week period in the summer, competitively selects both teachers and researchers and pairs them to conduct a focused research activity, work together on various phases of the study, participate in a journal club, and present results in a mentored poster session open to the university and community at the end of the six weeks (Tapprich, W., Grandgenett, N., Leas, H., Rhodie, S., Shuster, R., Schaben, C., Cutucache, C.; 2016). The summer program is followed by continued engagement in the next academic year as the pairs of teachers and faculty continue to refine the research, work on professional outcomes such as articles and presentations, and having the participating teacher bring their students to campus to tour the laboratories. Teachers learn deep research skills, and university faculty often learn some pedagogical tips from the teachers. These benefits are mutualistic. Teachers are also committed to translate their research into the classroom and researchers are committed to assist with this translation.

Dual Pathways for Undergraduate Teacher Preparation: Future STEM teachers who are preservice teachers at the undergraduate level today need to achieve a relatively deep content knowledge and competencies if they are to later take further coursework within a discipline, and to support Advanced Placement (AP) or Dual Enrollment (DE) teaching roles (National Academies of Sciences, Engineering, and Medicine, 2016; National Science and Technology Council, 2018) and to contribute effectively to STEM P-16 pathways. For example, AP and DE both require disciplinary graduate work by a teacher to justify these courses offered at a high school. At UNO, our collaborative STEM approach has produced dual pathways in the disciplines of mathematics, physics, chemistry, biology and geology/geography where students earn a degree in their respective disciplinary departments while also being certified to teach by the College of Education. With good advising, the students can and do achieve a "double degree", pairing a degree in their discipline, with one from the College of Education. Thus, a future mathematics teacher may get both a mathematics B.S. degree, along with an education B.S. degree. Majors are thus gained, not lost by either college. Thanks in part to this program, in a remarkably short time, the teaching preparation pipeline for STEM teachers has greatly expanded. For example, in mathematics, where the dual program was put in place in 2015, the program went from graduating about 2 or 3 secondary

mathematics teachers a year, to an average of 12 teachers a year in 2015 to 2018, with most of them as double majors. Chemistry and Physics joined in 2015 and went from about one graduate about every other year, to enrollments now that would support expectations for 3 or 4 per year each in 2019 and beyond. Biology has a dozen enrollees and a pathway in Geography/Geology is underway. Further, institutional grants for significant student support in these pathways, from the National Science Foundation Noyce program have already helped to support these teachers, with more than $3M shared across STEM teaching majors. Most importantly, teachers graduating in these dual pathway programs are also now ready to continue their coursework journey at the graduate level as nearly all of these teachers have an undergraduate disciplinary degree. Currently for example, about 60% of the mathematics teachers in this pathway enroll in a graduate course within the first or second year of their teaching as faculty follow up with them.

Innovative Undergraduate STEM Courses for All Students: Well-done and interesting STEM courses are certainly the "life blood" of STEM excellence on a campus, especially at the freshman level, where students are getting interested in particular college programs or majors (National Science and Technology Council, 2018). From an initial base of serving P-12 teacher preparation well, some excellent general education courses have surfaced. Gratefully, these opportunities are often supported by external grants that particularly strive to engage students. For example, the UNO Departments of Computer Science, Mathematics, and Teacher Education, came together to produce a course called "Introduction to Mathematical and Computational Thinking" which teaches algebra within the context of computer programming, using an open source visual computer programming language that was developed, refined, and researched by a faculty team led by professor in Computer Science (Winter, Love, Corritore, 2016). This general education mathematics course received initial funding from the National Science Foundation, and although initially designed with teachers in mind, it is now offered for all majors and is an alternative to the traditional college algebra requirement. Another example of such interdisciplinary STEM coursework is a general education science course developed by the Departments of Teacher Education, Physics, and Chemistry called: "Science Methods and Design" which has students conceptualize, launch, and analyze research data from a high-altitude balloon experiment. This course, as initially funded for teachers by the NASA Nebraska Space Grant, is now a course fully available to the campus, and has multiple instructors across STEM departments helping to refine and teach it. Such course-based undergraduate research experiences are increasingly available across UNO. In addition, many of our STEM students that have scholarships are required to work within UNO STEM youth outreach, and engage in educational research, as part of their summer coursework or ongoing scholarship experiences, which has shown to also be professional impactful for them as well as providing excellent role models youth attending the camps (Reding, Squires, Grandgenett**,** Keller, Grandgenett, Hodge, Argo, and Jacobberger, 2017). See https://eric.ed.gov/?id=EJ1126675.

The Citywide STEM Ecosystem: The extensive collaboration in STEM at UNO has also resulted in a new community effort, starting in 2017 that is UNO-led with the Henry

Doorly Zoo and Aquarium, and called the "Omaha Citywide STEM Ecosystem". This collaborative organization is only one of 56 such citywide ecosystems in the United States, and only 1 of 3 with a director that is externally funded (and a university employee). The Ecosystem includes more than 80 organizations across the city and more than 750 organizational representatives attending various events. The Ecosystem has facilitated a variety of STEM initiatives, such as contextual STEM workshops particularly focused on P-16 instruction, like "mathematics with an architect", "mathematics with a chef", "mathematics at the aquarium", "virtual reality in learning", and "physical spaces conducive to learning" to name just a few. (See https://omahastem.com/ for more context.) Further, all 13 area school districts and their teachers, representing more than 100,000, P-12 students actively participate, and draw upon the Ecosystem as a way to help to support their own students, including enhancing access to informal camps and afterschool programs. Many Omaha Ecosystem programs actively seek to engage students and teachers in community-based inquiry-based learning, citizen science research, student internships, and many other high engagement strategies. Although the impacts of the new Ecosystem are not fully known yet, signs are encouraging, with accomplishments such as a monthly STEM column in an Omaha Public School newsletter that distributed to more than 50,000 families with STEM engagement tips, 14 large scale STEM community networking events of 100-200 participants (and involving more than 700 different community representatives), three UNO related grants that use the Ecosystem for broader impacts, and new recruitment opportunities for bringing teachers into the graduate program, where for example, 14 teachers were successfully recruited via the Ecosystem for a special UNO STEM Learning Tools graduate course held at the Zoo.

STEM Community Chairs: Assisted by a very knowledgeable retired business leader, Dr. George Haddix, an innovative UNO leadership structure, called "community chairs" was established in 2010. These endowed chair positions have leadership responsibilities for wider community engagement, with release time, a small budget, and an administrative status to work across colleges, and to particularly engage with P-12 teachers and schools. (Grandgenett, N., Edick, N., Boocker, D., Ali, H., Hodge, A., Dorn, B., Cutucache, C. (2015). For details see https://journals.iupui.edu/index.php/muj/article/view/20989). Starting with a single STEM community chair in early 2010, there is now a team of five different STEM community chairs at UNO (based in teacher education, mathematics, biology, computer science, and physics), and a total of six other community chairs across the campus. The community chair teams have led or participated on interdisciplinary STEM grant teams that have been responsible for $35 million in external funding during the last 5 years, with most of the grants funded by the National Science Foundation and focused on supporting innovations in P-16 STEM teaching and learning, and research as a pedagogical approach. Many of these STEM grants have had extended collaboration oriented impacts, as for example, the NSF DRK-12 funded *Silicon Prairie Initiative for Robotics in Information Technology (SPIRIT),* NSF #0733228, trained over 400 Nebraska teachers, while creating more than 300 STEM lessons for the use of educational robots within P12 mathematics and science classes as an instructional tool. The program also worked collaboratively with other Nebraska robotics projects that

focused on informal education, based out of the University of Nebraska-Lincoln, and collectively finding significant growth in formal and informal teacher STEM practices, perceptions, and planning, as projects worked strategically across Nebraska to refine the project impact modeling for both formal and informal educators (Grandgenett, Ostler, Topp, Goeman, 2012; Nugent, Barker, Grandgenett, 2015; Nugent, Barker, Welch, Grandgenett, Nelson, 2016).

Strategic Planning:
The community chairs have also developed two detailed STEM Strategic Plans for campus, one covering 2013-2017, and the other looking forward from 2018 to 2023. The strategic planning process had the collaboration of more than 50 different faculty across 12 different UNO STEM related departments. The increasingly strategic campus collaboration for effective STEM P16 pathways, has also led the STEM faculty to collectively propose a STEM Teaching, Research and Inquiry-based Learning Center or "STEM TRAILS Center", now being considered by the Board of Regents. This Center will undertake many STEM Phase 2 support mechanisms for campus, such as wider faculty interdisciplinary training, grant writing for STEM P-16 initiatives, focused evaluation consulting, and various graduate assistant and post doctoral support mechanisms. It will also have a key focus on expanding "research as pedagogy" across the UNO campus, so as to offer all STEM students one or more hands on research experiences that immerse them in and excite them about their major. Further, it will be a focal point for wider external collaboration, not only with the local STEM Ecosystem community, but also with other universities and colleges across the United States.

**Stakeholder Implications for STEM Silo Bulldozing**

When considering such programs as a reader though, it is important to note though that STEM "Silo Bulldozing" is certainly not easy, and breaking down the historical STEM barriers on a campus needs to be considered as a frequently political and stressful context, as it often involves departmental "program turf" in one way or another. Most importantly, it takes very focused strategic planning at a variety of levels to help to systematically and thoughtfully address such barriers for STEM innovation (National Science and Technology Council, 2018). In addition, trust building is certainly at the center of this strategic planning process and the related collaboration, as many of our UNO programs had extended conversations that required people to continue to contribute to the planning, such as when dual undergraduate pathways were first put in place. Examples of primary stakeholder groups and implications are:

- Researchers – For researchers, we have found that Discipline-Based Educational Research, or engaging in educational research from the base of a discipline (such as for program retention, coursework improvement, etc.) can be a powerful mechanism for engaging faculty, as it is an opportunity for teams of faculty to collaboratively publish and to externally fund their efforts. As part of a team, a disciplinary researcher has expertise in content (i.e. "expert teacher") while combining skills in cognitive sciences for the "application and assessment" component; thus making a powerful research contribution. Furthermore, combining these two synergistic areas of expertise can also be very powerful for trust building, as the faculty typically see a productive collaboration, and can also often find real contributions to their careers (e.g. publications and grants, or

as a mechanisms within disciplinary grants for broader impacts by having a funded P-12 engagement component).

- Teacher educators – For teacher educators, particularly in Colleges of Education, it is important to realize that a close working relationship with disciplinary colleagues in other departments can enhance program(s) and may well become a catalyst to increased enrollments rather than decreased ones in a teacher education program. Engaged disciplinary partners in other colleges can also provide strong encouragement to disciplinary students to consider teaching, when such faculty are a part of preparing these teachers. Further, with encouragement and collaboration, disciplinary colleagues often begin to employ some model pedagogical practices, which reinforce the learning fundamentals already integrated into educational coursework.

- P-12 schools – For P-12 schools, it is important to realize that hiring a well-qualified science teacher that can teach deeply in a particular discipline, is a greater long-term contribution to a school then a more generalized science teacher, who often is limited to lower level coursework, and is often locked out of any graduate coursework on content. For example, a Physics teacher with a disciplinary degree in Physics, who is ready to take physics graduate coursework will eventually be able to help the school offer dual enrollment coursework in partnership with a local university, and will often have a great relationship with university faculty to refine such coursework, while a general science teacher, who has only had lower level coursework, will most likely not be ever able to teach a dual enrollment course.

- Policy makers – For policy makers, and particularly administrators at the university, it is critical to encourage faculty and departments to try to put aside turf considerations for various experimental efforts. At UNO, we had departmental, college, and university administrators that were often very willing to take a chance and who worked collaboratively to build trust across STEM departments and colleges. At times, they attended joint meetings, and other times simply invited faculty outside of a department or college to collaborate on something important, such as student retention. Most importantly though, administrators need to encourage departments to accept contributions like interdisciplinary STEM grants, disciplinary based education research publications, and other collaborative professional endeavors to count toward a faculty member's reappointment, promotion, and tenure process. Policy makers at the state and national level need to be engaged also, and need to try to see P-16 STEM education as collaborative pathways, where all partners can be resources. For example, in Nebraska, 92 disciplinary and education professors across the University of Nebraska system provided feedback and refinements on the 2017 Nebraska Science Standards to the Nebraska Department of Education (NDE) at their request and often we serve on panels sharing these innovations with lawmakers. Finally, some of those university faculty continue to work with NDE on various initiatives, and they themselves have a better understanding of P-16 Education.

Thus, in summary, the collaborative STEM "bulldozing" journey at UNO began with a strong P-16 commitment to jointly preparing high quality STEM teachers, and enhancing the skillset of

current STEM teachers through research-based experiences. As a result, these initiatives have added to the campus culture and departmental silos have been significantly reduced, and although certainly some are still present, they are increasingly eroding as the bulldozer routinely bumps into them with new initiatives and successes. The innovation of jointly preparing STEM teachers and building programs across disciplines to do so made perfect sense for a metropolitan university like UNO, and the trust it built was in many ways the bulldozer fuel. The wider programmatic dialogues that explore possibilities for all STEM students have become increasingly more common and spontaneous, as more and more faculty take an interest and share responsibility for high-quality STEM programming. Thus, although STEM bulldozing is not easy and is often a bit messy, it is increasingly fun as more machines get underway, and more and more faculty put themselves into the driver's seat.

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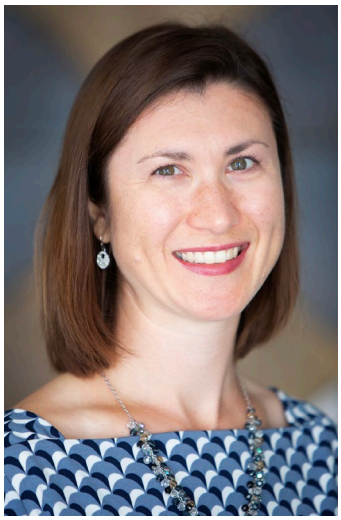

**Dr. Christine E. Cutucache, Ph.D.,** is the Haddix Community Chair of Science and Associate Professor of Biology at the University of Nebraska at Omaha (UNO). Dr. Cutucache is a tumor immunologist turned science educator. During her tenure, Dr. Cutucache has secured more than $8.8 million in funding, and has published over 30 peer-reviewed articles on her research. She has also published 3 books. She has delivered over 40 presentations on her work around the world with most including undergraduate research students as co-authors or co-presenters. Her research lab is diverse in studying both tumor immunology (specifically tumor-induced immunosuppression in B- and T-cell leukemias and lymphomas) as well as Discipline-Based Education Research (so called 'DBER' or science education). She is interested in student-centered, inquiry-based practices to improve learning outcomes, including critical thinking and metacognition. Her personal philosophy is that engaging learners in research experiences is the most effective pedagogical instrument. Dr. Cutucache served as the founder of the now Nebraska-wide Nebraska STEM 4U (NE STEM 4U) program, which engages K-8 youth in high quality out-of-school time activities in STEM via problem-based learning. To-date, this program has engaged 5,000 youth through sustainable, academic year-based programming. The NE STEM 4U project is a collaborative project between the University and Community Partners and stakeholders. Dr. Cutucache was a founding member of the Teacher-Researcher Partnership Program and is Principle Investigator of the NSF Noyce Science project. Her lifetime goal is to engage as many lifelong learners as possible in genuine research projects.

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**Dr. William E. Tapprich Ph.D.,** is the Sophie and Feodora Kahn Professor of Biology at the University of Nebraska at Omaha (UNO). He is an RNA biochemist, virologist and educational researcher. In basic research, he studies the structure and function of viral RNA genomes. He has served as PI on 13 basic research grants with total funding of $4.3 million. In discipline-based education research (DBER) and studies best practices in biology education with an emphasis on undergraduate research. He has served as PI on 3 and CoPI on 12 DBER grants with total funding of $4.4 million. The majority of his funding for both DBER and basic research has come from NIH and NSF. Dr. Tapprich routinely delivers course-based undergraduate research experiences in his teaching. As PI on an NSF RCN-UBE award, Dr. Tapprich designs and implements assessment instruments to evaluate the educational impact of bioinformatics teaching resources delivered to life science students. Dr. Tapprich is actively involved in projects that enhance discipline-specific education for K-12 teachers and students. As Co-PI on the NSF Noyce grant he contributes to the dual-pathway degree program where pre-

service teachers obtain a Bachelor's degree in a science discipline while pursuing teaching certification in education. As Co-PI in the Nebraska STEM 4U (NE STEM 4U) program, he contributes to efforts that engage K-8 students in out-of-school time problem-based learning activities. As PI of the Teacher-Researcher Partnership Program (TRPP), Dr. Tapprich organizes and mentors in-service teachers in authentic STEM research projects that are translated back into K-12 classrooms. In all aspects of his teaching and research, Dr. Tapprich seeks to provide research experiences to learners at all levels.

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**Dr. Brian Dorn, Ph.D.** is an Associate Professor of Computer Science and holds the Union Pacific Community Chair in Computer Science Education at the University of Nebraska at Omaha. Along with colleagues and students in the BRIDGE lab, he conducts human-centered computing research with a particular emphasis on education and the learning sciences. He actively designs and evaluates educational technology to support the teaching and learning of computing content. As a community chair, he also is actively involved in advocacy and training work to support universal access to computing education in primary and secondary schools across Nebraska. He holds a Ph.D. from the Georgia Institute of Technology, is an active member of the ACM, ISLS, and AERA, and serves as co-editor of the journal Computer Science Education. He has led initiatives at UNO that have established a supplemental endorsement in information technology that is focused on Computer Science, and a M.S. degree program in Computer Science Education, a degree program that is one of the first in the nation and popular with teachers in the Omaha area. He is a frequent publisher, international presenter, and grant PI related to innovations in P16 computer science education programs.

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