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Research-to-action multidisciplinary projects: an undergraduate convergence research course

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This paper presents the Research-to-Action Multidisciplinary Project (RAMP) course, a model for training both undergraduates and faculty in convergence research. Competencies needed to achieve convergence are still emerging as part of the literature. As they emerge, faculty and students need new ways to learn these competencies as traditional, uni-disciplinary education does not provide these opportunities. This can only happen through an opportunity for hands-on, applied learning. The RAMP course addresses wicked problems through related group projects to facilitate faculty and student co-development of meta-cognitive skills for integration across disciplines. Through faculty interviews, this paper evaluates the success of the RAMP course model in helping faculty develop their own convergence research skills needed to integrate knowledge across disciplines in diverse teams. The RAMP model offers a promising approach to undergraduate convergence research education that equips both students and faculty with essential convergence skills for real-world problem-solving. However, challenges do exist in this model at the institutional, faculty, course design, and course implementation levels. Institutional barriers include bureaucratic hurdles to interdisciplinary team teaching as well as securing project funding. Overcoming these hurdles requires carving new institutional pathways, investing in integrative roles, and leveraging shared, interdisciplinary funding opportunities. By tackling challenges at institutional and organizational levels, the model can be improved to maximize the beneficial outcomes for faculty and students.

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Introduction

To face the ever growing number of challenges with interdependent consequences, such as climate change and the development of artificial intelligence, students and researchers must re-imagine the way problems are approached. These complex, interdependent challenges are often categorized as wicked problems. Ackoff (1974) describes these "messy" challenges as "a system of problems" in which the whole cannot be addressed by solving any one independently. Wicked problems are large-scale societal issues with high levels of uncertainty in intervention outcomes, confounding or conflicting processes, and significant social and cultural contexts (Rittel and Webber, 1973).

Addressing wicked problems requires an approach to problem-solving that contextualizes technical interventions within the political, social, and cultural systems in which nuanced decisions are made and, simultaneously, requires more problem solvers who can bridge the technical with the social (Fiore, 2008; Head and Alford, 2015). A convergence approach uses methods in which researchers integrate knowledge across disciplines and has been identified as essential to addressing wicked problems by research funding agencies such as the National Science Foundation ("NSF's 10 Big Ideas", 2019). Convergence research builds on transdisciplinary approaches to integrating knowledge across multiple disciplines, focusing on how to bring in a multitude of perspectives including those beyond academic disciplines to address compelling societal challenges by explicitly working to co-create new more holistic knowledge than the sum of what could be generated from individual disciplines (Sundstrom et al. 2023).

As a newly defined term, convergence is often conflated with multi-, inter-, and transdisciplinarity, resulting in a lack of clarity in much of the literature as the difference between these terms continues to be clarified. Additionally, theories and methods from inter- and transdisciplinary literature are drawn upon heavily and often directly inform the practice of convergence research and education as well as the development of convergence-specific approaches, Within this paper, convergence research is defined as research that integrates knowledge across academic disciplines including natural, social, and physical sciences as well as diverse non-academic stakeholder groups for the purpose of addressing complex problems. Because interdisciplinarity is considered to be a necessary condition for convergence research, the term "interdisciplinary" is commonly used in this paper to refer specifically to collaboration among different disciplines that may not be specific to convergence, but is a requirement to enable it.

However, the present institutional structure at most universities does little to prepare students and faculty to work across disciplinary boundaries. In an educational system siloed by academic disciplines, helping students and faculty effectively integrate knowledge across disciplines can: (1) build fluency in the habits of mind necessary to integrate knowledge from multiple realms of expertise into cohesive approaches to inquiry, (2) prepare students moving into roles of leadership and faculty to be more conscious of, and hopefully take into account, the second- and third-order consequences of the impacts of their decisions, and (3) create better civic awareness of the interdependence of the wicked problems societies face, and will continue to face in the future (Fiore et al. 2019). Competencies such as individual habits of mind, interpersonal collaboration, and systems thinking are particularly important for more use-inspired research addressing broad societal challenges in academia, the private sector, and beyond (Spelt et al. 2009). A convergence approach requires research methods that integrate knowledge across physical, natural, and social sciences through the creation of a shared research framework among collaborators (National Research Council, 2014). This integration creates new knowledge from a range of expertise. Success in such integration depends upon the capacity to discern appropriate interaction points between expertise areas and communicate effectively across boundaries while anchored by a shared goal (Bammer, 2013; Klein, 1996).

The task of understanding and creating approaches to address wicked problems requires a different set of skills in a convergence context compared with the uni-disciplinary approaches to research in which most students are currently trained (Love et al. 2022). Importantly, these methods are part of the emerging disciplines called Integration and Implementation Sciences (I2S) and Science of Team Science (SciTS), the principles and approaches of which enable recognition, integration, and synthesis of relevant concepts to help weave ideas from multiple epistemic directions into a coherent path toward addressing wicked problems (Bammer 2003; Stokols et al. 2008). It is important to note that I2S and SciTS methods, while encouraging the blending of expertise across multiple fields and sectors, do not advocate simply increasing the breadth of expertise a convergent scholar must hold to tackle a problem. Rather, these approaches enable integrators to surface and discern contributions from multiple vantage points. To prepare students and faculty for engaging with wicked problems, we need to expand the opportunities in higher education to gain these skills in convergence research (Fiore et al. 2019; James Jacob, 2015). We must equip students and faculty with the skills to integrate knowledge across disciplines so that they can be leaders in solving the world's most pressing challenges (e.g., food systems sustainability and climate resilience).

The Research-to-Action Multidisciplinary Projects (RAMP) is a course model designed to provide convergence education rooted in evidence-based integration practices through a hands-on project-based learning experience for undergraduates, developed and applied at Appalachian State University. This model acknowledges the parallel learning objectives for the team-teaching faculty who bring their variety of disciplines to the convergent research experience. Because convergence represents a set of competencies becoming better understood as critical to addressing societal problems, its absorption into the way research teams address wicked problems requires a broad upskilling across the entire career arc. Though interdisciplinary studies have been an established and developing presence in higher education for decades, the broader application of convergence competencies has not permeated typical faculty pathways (Bammer et al. 2020; Pennington et al. 2013). As part of the design of the RAMP model, the faculty must also onboard new abilities and habits of mind to create shared understanding across different epistemologies and pedagogical approaches, and importantly, participate in actively learning from one another and in the process, demonstrating their own intellectual humility and visible learning processes to the students.

In a study of the Fall 2022 iteration of the RAMP course, Rickabaugh and Siegel (2025) present preliminary evidence indicating that, one-year post completion of the course, students retain the value of collaboration and maintain the habits of mind necessary for successful convergent research endeavors. With specific attention to the development of cognitive competencies including understanding the nature of complex problems, transdisciplinary team learning, and collaborative problem-solving strategies, the study highlights the RAMP course's efficacy for instilling these concepts early on in undergraduate students' academic experience. For example, 100% of student survey respondents strongly agree(d) that they understand what convergence research is as a result of completing the course.

In this paper, we outline the RAMP model including (1) the institutional structures utilized to create and maintain an interdisciplinary research course, (2) course structures implemented to

Table 1 Core competencies explored by both faculty and students in the RAMP course.

Core competency	Definition
Individual Habits of Mind	
Epistemic Humility	A recognition that one is reliant on others' expertise to have a complete understanding of a topic, and that on certain topics, no confidence is possible. It is also a keen awareness of our vulnerability to error.[a]
Interdependence	An awareness that projects within a team are inherently connected based on shared methods, knowledge input and outputs, or impact areas.[a]
Co-creation of Knowledge	Integration of multiple sources of knowledge through inviting non-academic stakeholders to aid in the design of methods and interpretation of results in applied research contexts.[b]
Convergence Research Skills	
Integration	An ability to recognize the underlying philosophical differences that occur across disciplines to navigate these differences effectively on a team.[c]
Systems Thinking	Defined by the ability to contextualize a project within a broader system to understand how it might interact with other natural, social, and physical systems.[d]
Interpersonal Team Skills	Effective communication in divserse teams and navigation of team dynamics including interpersonal relationship building.[c]

[a](Roco, 2016).
[b](Mauser et al. 2013).
[c](Fiore et al. 2019).
[d](Kim, 2016).

teach convergence research methods, and (3) a case study of the Fall 2023 RAMP: Wicked Environmental Problems course. Using a qualitative case study methodology, we examine the whether and in what ways a course, such as RAMP, can facilitate faculty learning outcomes, in contrast to the more usual student-focused teaching evaluation.

The RAMP model

RAMP courses are designed to provide students and faculty with the opportunity to engage in convergence research and gain the skills to integrate knowledge across many disciplines. The vehicle serves as a "ramp" that elevates the co-teaching faculty's capacity for and engagement in convergent collaborations that transcend the specific course and can serve as the social infrastructure on which they can build longer-term research programs.

Course structures. The course model was co-created and piloted by two university-spanning institutions that are structurally and bureaucratically positioned to effectively work across multiple academic colleges at Appalachian State: an interdisciplinary research institute, Research Institute for Environment, Energy, and Economics, or RIEEE, and the Honors College. Each semester-long RAMP course, faculty and students study a wicked problem in an applied, local context. This program was modeled after a specific instance of the Bass Connections program at Duke University, an interdisciplinary project-based learning experience for undergraduates (Balleisen et al. 2023), co-created by the same faculty member who brought RAMP to Appalachian State. The original Bass Connections course was called "DEcisions on Complex Interdisciplinary Problems of Health and Environmental Risk", or DECIPHER (Decisions on Complex Interdisciplinary Problems of Health and Environmental Risk (D-CIPHER) (2017–2018)).

RAMP promoted co-learning of convergence research skills in both faculty and students. Convergence research differs from that of multi- and interdisciplinary research through the complete integration of knowledge and methods from multiple disciplines to collectively address wicked problems (Roco, 2020). Elements of active learning and project-based learning (PBL) pedagogies were integrated into the RAMP structure to model this research framework through team-based projects in which convergence is scaffolded by the course structure. PBL courses center mentored, applied research projects within a classroom environment. Anchored to a shared topic of interest, these projects provided the opportunity for faculty and students to hone their skills in critical thinking, creativity, and collaboration to address wicked problems (Balleisen et al. 2023; Kokotsaki et al. 2016). Through an adapted PBL framework RAMP also fostered the development of the construction-of-understanding ecosystem necessary for active learning as defined by Lombardi et al. (2021). In this ecosystem, active learning is defined by a student's opportunity to have agency over their own learning through hands-on experiences with scientific concepts, data, and analysis. Multiple learning pathways exist in this ecosystem, including between students and their peers and students and faculty; student self-reflection is considered another learning pathway (McGregor, 2017). The RAMP model was designed to also promote learning pathways between faculty learning from one another as they co-teach the course as well as faculty learning through self-reflection.

The course objectives prioritized developing participants' abilities to collaboratively investigate physical and social scientific events and circumstances with a focus on use-inspired research (see the Supplemental Information for more details about the course objectives). The fields of I2S and SciTS have identified the meta-competencies necessary to engage in effective team research: (1) skills to manage interpersonal and team dynamics, (2) the metacognition to recognize and integrate different ways of knowing, (3) habits of mind necessary to collaborate with others, and (4) disciplinary content expertise (Bosque-Pérez et al. 2016; Nurius and Kemp, 2019). These expand upon the competencies associated with PBL as integration requires both critical thinking and creativity. The development of interpersonal and team management skills are also the foundation for effective collaboration.

The RAMP course focused on the development of individual habits of mind and convergence research skills including integration, systems thinking, and interpersonal team skills (Table 1) to supplement students' major courses that provide them with disciplinary content expertise. When asked to compare their experiences in the RAMP course to experiences in traditional, unidisciplinary lectures, respondents (students) indicated that, as a result of RAMP, they effectively developed these skills and are better equipped to effectively work in transdisciplinary teams and engage in convergent research. Students reported possessing the necessary habits of mind for convergence research, such as being able to understand the perspectives of team members from different disciplines and appreciating the

need for integration across disciplines. They also indicated they onboarded convergence research skills such as understanding the mechanisms for addressing complex problems, understanding team dynamics for effective collaboration, and recognizing and managing differences across disciplines (Rickabaugh and Siegel, 2025).

The RAMP class focused on developing narrowly defined small-group projects related to a single wicked problem, such as climate change or phosphorus sustainability. Taken together, the projects selected integrate a broad array of perspectives and methodologies for (1) investigating questions that impact individual, local, and political decisions through systems thinking and integration and (2) understanding how smaller projects intersect with the wicked problem as a whole through the practice of the habits of mind (Table 1). These projects were often stakeholder-engaged, highlighting the importance of co-creation of knowledge and integration across sectors as well as disciplines. This set of projects acted as a boundary object—a concept or artifact that researchers can use to anchor themselves to a shared conceptualization of the problem or goal they are pursuing from their individual vantage points; the boundary object acts as a mixing zone where project members can contextualize their contributions within a specific complex problem, and over time they can also understand the relationship of other types of knowledge to the same problem, without needing to onboard that expertise directly (Leigh Star and Griesemer, 1989). They illustrated interdependence, providing students and faculty with a more comprehensive visibility into a varied toolbox of methods for evaluating wicked problems and potential ways to address them (see Table 1 for more details about the core competencies taught).

Faculty and students undertook research projects within self-selected student groups from broad disciplinary backgrounds, working closely with a faculty mentor. In each case, the faculty member began the experience by proposing one or more general questions and outlining available techniques that might be used to seek an answer. An emphasis was placed on student autonomy and student involvement in defining the research objectives, as well as in specific experiment design and execution. The degree of autonomy in choosing the underlying question(s) to be asked represents a distinction of the RAMP model from other course-based undergraduate research experiences (CUREs) or other inquiry-based research classes (Williams and Dries, 2022).

The first two weeks of the course were dedicated to (1) lectures providing the background knowledge necessary for students to gain a surface-level understanding of the focal wicked problem, and (2) placing students in interdisciplinary groups to complete these research projects under the mentorship of a participating faculty member. Background lectures helped to create a foundation of knowledge students needed to understand and approach solving aspects of a wicked problem, and provided a menu of disciplinary resources that participants could refer back to along their research project paths. With this context established, projects were then selected and adapted.

Once research teams were formed and projects defined, the class time was divided into two session types: seminars and project work periods. This course emphasized out-of-classroom research, but still utilized occasional meetings to expand students' knowledge on the common topic and encourage cross-project convergence. These weekly meetings included a mixture of discussion periods to encourage convergence across projects to promote integration and systems thinking, and lectures provided by faculty or guest speakers with expertise relevant to the course theme, in which students were encouraged to practice epistemic humility.

Assignments in this course guided students through the research process, allowing students to apply knowledge gained through research and lectures, and track student progress across projects. The first assignment students completed with their project group members was a project plan agreement (see template in the Supplemental Information). This agreement facilitated the alignment of their personal and group goals with those of the faculty member leading the project (Bennett and Gadlin, 2019). This also helped students and faculty to gain interpersonal team skills and identify potential points of tension before conflict arises (Cravens et al. 2022).

Student research progress was evaluated based on a research report that was developed throughout the course, starting with a literature review and proposal at the beginning of the semester (see template in Supplemental Information). Once projects were underway, bi-weekly research updates were required. These updates included a summary of progress since the last update, research plans for the next two weeks, and, later in the semester, a summary of research findings in the form of tables or figures. Alongside research updates, students were required to submit reflections on the course content and experience to encourage reflection on the habits of mind and convergence research skills the course is designed to bolster (see prompts for reflections and research updates in Supplemental Information).

Faculty co-designed reflection prompts to guide students through the metacognitive thought processes necessary to understand their mental models that impact the research process (Boon and Van Baalen, 2018). Mental models are "isolated knowledge structures that students use to make sense of the world" (Shepardson et al. 2007, 330). Students were encouraged to first identify their mental models and then examine how they have changed in the context of the project groups. The Bass Connections Program at Duke University has highlighted the importance of providing students the opportunity to reflect as an essential part of successful interdisciplinary experiences such as this (Balleisen et al. 2023). These reflections were an important aspect of the constructivist approach to learning employed in the RAMP course (Howlett et al. 2016; Rogers, 2001). Development of convergence research skills was bolstered through ample opportunities for self-reflection to seed metacognitive processes that are key to team science approaches and to encourage active engagement in skills development throughout course experiences (Fiore, 2008; Howes and O'Neil, 2022; Kokotsaki et al. 2016).

The RAMP course relied on these qualitative evaluations of learning and the course activities to measure success. Students were required to submit a longer reflection paper at the end of the semester where they were asked about (1) their expectations entering their course and whether they were met, (2) the strengths and weaknesses of the course, (3) how the interdisciplinarity of both the students and faculty impacted their experience, and (4) how well the content of the course and research connected throughout. These questions helped determine the degree to which convergence is occurring from a student perspective and identify the course activities that contribute to that success. In addition to gathering student reflections, faculty were asked to attend a facilitated discussion to critically analyze the course structure, content, and organization. They were asked to determine whether course activities led to the intended learning outcomes and success in the research projects.

Institutional structures. Institutional structures at universities can benefit and hinder the creation of interdisciplinary course development (McCoy and Gardner, 2012). In this section, we explore three organizational pathways built to make RAMP possible: (1) research funding for the course, and (2) financial

structures to compensate faculty, and (3) institutional scaffolding for multidisciplinary.

Building a research-centric course model like RAMP within a university structure can present some challenges in terms of administrative and financial pathways that may need to be created. In universities with less heavily resourced research enterprises, there might not be funds available or funding pathways established to support new or additional research projects. Depending upon faculty pay structures and teaching expectations, it may also be challenging to identify funding pathways to provide additional compensation to faculty or to the faculty in department who cover their normal teaching responsibilities if their typical courses are reassigned.

In the example presented in this paper, the course was funded jointly through the Honors College at Appalachian State and one of two research institutes at the university, the Research Institute for Environment, Energy, and Economics (Research Institute for Environment, Energy and Economics). RAMP faculty were provided with additional teaching stipends through the Honors College and RIEEE, and research funding was sourced from external grants and internal RIEEE awards. Faculty were recruited based on existing research interests or projects related to the chosen wicked problem. Many projects already fit within the RAMP structures because there was existing locally relevant and hands-on research at Appalachian State. Aligned with this, existing projects were adapted to the RAMP structure and timeline.

Hosting RAMP through the Honors College more easily enables cross-college course collaboration due to its independence from disciplinary structures. At Appalachian State, the Honors College is an institutional unit that operates between colleges, encompassing students of all disciplines and majors. It allows faculty to participate in a shared course that does not force them to navigate the otherwise inherent competition between departmental course registration numbers. On the other hand, for similar reasons, Honors College courses sometimes must be taught in addition to normal course load expectations. For RAMP and many similar programs such as Clemson University's Creative Inquiry and Duke's Bass Connections, most faculty are not given a course release from their department to participate. An additional benefit of hosting RAMP through the Honors College is the ability to list and advertise the course as discipline-agnostic to an established pool of motivated students with varied academic interests capable of engaging with independent research at the sophomore level. This helps with both broad visibility and recruitment. Fully one-half of the seats are not restricted solely for students in the honors program, so enrollment access is not strictly limited.

Case study: the wicked phosphorus challenge

In the Fall of 2023, the RAMP course was offered for a third time and a second time with the chosen wicked problem of phosphorus sustainability. As a society, we are reliant on the application of nitrogen and phosphorus (P) onto agricultural fields to maintain the necessary crop yields to feed our world's growing population. However, excess nutrients in our surface waters have caused large-scale, catastrophic environmental damage. P is of particular concern due to the additional environmental degradation caused by mining operations to source phosphate rock and its finite stores. P sustainability is critical to issues of food security, geopolitical stability, and environmental conservation (Chowdhury et al. 2017).

This RAMP topic was chosen, in part, due to Appalachian State's participation in the Science and Technologies for Phosphorus Sustainability (STEPS) Center, a National Science Foundation-funded Science and Technology Center. The STEPS mission is to support both a reduction of the world's reliance on mined phosphates and the reduction of P loss from point and nonpoint sources by 25% in the next 25 years. Research efforts in the center are broad and varying, integrating knowledge across disciplines including agricultural sciences, materials engineering, environmental engineering, political science, and economics. Appalachian State is one of ten universities contributing to the center's research efforts (U.S. NSF Award #2019435).

The North Carolina High Country provides an ideal backdrop for students to engage in local, application-based research and collaborate with local government, land owners, farmers, and other stakeholders to characterize regional P flows, evaluate reduction strategies and technologies, and define P sustainability for similar regions. As a small, mountainous region containing pristine headwaters, the region is an important area of study and application for P sustainability research and technologies developed through STEPS (Caldwell et al. 2023). The High Country is characterized by a tension between its growing population, the accompanying development, and smallholder agriculture; the region will soon reach critical decision points impacting P sustainability and the preservation of these pristine headwaters.

Projects for the 2023 iteration of RAMP were chosen based on a focus on agricultural P flows. Four faculty already funded by STEPS were asked to lead research projects within this course sub-theme. The purpose of introducing a sub-theme for the semester was to increase the subject matter overlap and the potential for convergence across projects. The subject matter of these projects spanned: (1) characterizing P content in soils across local farms (Sections "Phosphorus Partitioning in a Small Dairy as a Function of Grazing Intensity and Soil Depth" and "Quantifying P Storage in High Country Agricultural Soils"), (2) investigating plant physiologies that increase P uptake (Section "Keeping Phosphorus on Farms: Addressing the Problems of Agricultural Phosphorus Bioavailability and Retention Using Plants"), and (3) researching local governance structures that contribute to regulating P application to agricultural fields (section "Soil & Water Conservation District Advice Networks").

Methods. To evaluate faculty learning outcomes of the 2023 RAMP course, semi-structured interviews of the participating faculty were conducted as part of an exploratory analysis. These were conducted in compliance with Appalachian States IRB office, approval id: HS-25-27. Interview subjects were provided with a consent form prior to participation detailing the purpose of the study and any risks involved. All interviews occurred either through Zoom or in-person. They were recorded and transcribed for analysis.

Four interviews were conducted in total. Participants were identified through purposive sampling based on their participation as an instructor of the RAMP course (Palinkas et al. 2015). Their contact information was identified through the Appalachian State University website, and contact was initiated via email.

An interview script was developed based on research questions related to faculty learning outcomes of the course and faculty views of successful and unsuccessful aspects of the course. The guiding questions for the interview can be found in the supplementary information. Interviews lasted on average 22.5 min.

Interview transcripts were analyzed using ATLAS.ti software using thematic analysis methods (Braun and Clarke, 2006). These themes are captured in Table 2. Upon first review of interview transcripts, general themes were identified. An iterative approach was then used to identify sub-themes in interview responses.

Table 2 List of themes and subthemes used to qualitatively code the interview data.

Theme	Sub-theme	Definition
Classroom Dynamics—refers to the interpersonal dynamics between students and faculty during the course.	Communication	One way transfer of information and related skills.
	Faculty-Faculty Collaboration	Faculty working together to produce a research output.
	Faculty-Faculty Interactions	Faculty engaging with one another through discussion.
	Student-Faculty Interactions	Faculty engaging with students through discussion.
Course Factors—elements of the course that led to either the success or lack thereof in the course.	Lack of cohesiveness	Missing connective threads throughout projects and the course activities.
	Not enough time in the course	Time as a limitation to completing course projects and achieving stated learning objectives.
	Student diversity	Disciplinary diversity among students.
	Student engagement	Student engagement in the research and convergent elements of the course.
Course Metrics—outcomes of the course by which success or lack thereof was referenced.	Lack of meaningful research outcomes	A noted lack of research outputs that significantly contribute to the goals of the project.
	Student convergence skills	Any perceived gain of skills or knowledge of convergence research methods by the students of the course.
Individual habits of mind—demonstrated ways of faculty engaging with other course participants and research that increase convergence capacity across disciplines and projects.[a]	Co-creation of knowledge	Integration of multiple sources of knowledge through inviting non-academic stakeholders to aid in the design of methods and interpretation of results in applied research contexts.[b]
	Epistemic humility	A recognition that one is reliant on others' expertise to have a complete understanding of a topic, and that on certain topics, no confidence is possible. It is also a keen awareness of our vulnerability to error.[a]
	Interdependence	An awareness that projects within the course are inherently connected based on shared methods, knowledge input and outputs, or impact areas.[a]

[a](Roco, 2016).
[b](Mauser et al. 2013).

Phosphorus partitioning in a small dairy as a function of grazing intensity and soil depth. As an introduction to phosphorus sustainability, students were asked to consider mechanisms of phosphorus mobility in agricultural soil by collaborating with a local goat dairy. Prior stakeholder input from this farm suggested a desire to develop management practices to better retain P on fields and minimize any runoff into a creek running through the property. Students were taught to take soil core samples and to quantify both orthophosphate and total phosphorus using a colorimetric assay. Beyond this, students were given considerable space to develop an independent project.

An initial student suggestion was to use soil columns in the laboratory to understand P mobility, looking at the impact of various soil amendments. After a week of literature review and a robust group discussion, the laboratory-focused research direction was set aside in favor of field testing on the actual farm. The team began preparing to collect groundwater at depths up to 100 cm, with the intention of comparing phosphorus concentrations in groundwater up- and down-hill from a manure compost pile (a large source of P), thus quantifying P mobility at different soil depths. However, it soon became apparent that barring heavy rain, the wells at these shallow depths would afford minimal free flowing water for testing. With time in the semester running short, and with the blessing of the landowner and access to an excavator, the research team dug four soil pits to a depth of 90 cm, allowing comparison of soil P at different depths. In many regards, this last-minute change in research methodology allowed an alternative approach to address the same research question. However, the research team was not able to investigate the impact of soil amendments on P retention, which was the question most relevant to the farm. Flexibility and focus on the overall goal is key to the success of open-ended research experience in such a dynamic system and on a short timeline.

Quantifying P storage in high country agricultural soils. As part of a broader effort to quantify flows of P into and out of the High Country region, this project aimed to quantify the amount of P stored in agricultural soils on Christmas tree farms and determine how fertilizer application rates and cover crop use impacted the amount and vertical distribution of P in the soil column. This work was fundamental to co-developing solutions with stakeholders to increase P fertilizer use efficiency. Initial expectations were that students would participate in field sampling and laboratory analysis of soil samples and would interface with stakeholders in the NC Cooperative Extension and local farmers to design samping strategies and communicate their findings.

However, challenges arose into coordinating with additional farms during the semester, demonstrating that it takes considerable time and effort to establish trust between groups involved in addressing wicked problems. Instead of focusing on agricultural practices influencing P soil distributions, the group realigned the project expectations to focus on quantifying the amount of P stored in the soil of the one farm the group was able to sample.

Keeping phosphorus on farms: addressing the problems of agricultural phosphorus bioavailability and retention using plants. In order to understand how we might access existing stores of P that already exists within soils, the project "Keeping Phosphorus on Farms: Addressing the Problem of Agricultural Phosphorus Bioavailability and Retention Using Plants" sought to characterize how fungi and plants can work together to mobilize P in soils. In many soils, phosphorus exists in forms that are insoluble and inaccessible to plants, which need this nutrient for growth and development. Therefore, plants benefit from the ability of specific fungi make P available to their plant. To investigate these relationships, the faculty leading this

project planned several laboratory experiments but limited time availability caused the need for changes in the original project. Unforeseen logistical challenges occured including missing components to key experitments, limitations on laboratory space, and access issues as well as unavailability of equipment. Students also had limited time to spend in the laboratory and needed additional guidance in managing their time.

The project promoted convergence by integrating multiple disciplines, perspectives, and methodologies to address complex challenges related to phosphorus management and environmental sustainability. Community members and stakeholders (BAD Composting) were involved in the design, sample collection, and consideration of real-world applications, perspectives or potentials of the project. They also provided insights into the specific challenges and priorities related to phosphorus management in agricultural settings or environmental sustainability practices. Additionally, samples were shared between this group and the "Quantifying P storage in High Country agricultural soils" group. By integrating the work from other STEPS groups, this group compared legacy phosphorus and accumulation effects in different farming systems. Individually, both projects contributed to understanding the availability of P to plants and the retention of phosphorus in plants and the environment. Together the projects can reveal the beneficial roles of microbes in the interaction and environmental factors influencing phosphorus cycling in agricultural systems.

Soil and water conservation district advice networks. The focus of the project "Soil & Water Conservation District (SWCD) Advice Networks" on phosphorus sustainability addresses both governance and policy issues influencing management practices. Instead of investigating the enviro-technical aspects of SWCD policy, our project instead investigated the advice networks elected and appointed SWCD supervisors use to gather information about how those decisions are made when there are substantially fewer resources (Morris et al. 2021). The group modeled our research after Zeemering's (2021) article investigating from whom Bay Area municipal elected officials seek information and advice.

This group faced research challenges as well as logistical challenges developing a survey for SWCD supervisors that could capture these ideas. One challenge was that students were all quite familiar with applications of network analysis, but had not seen how the mechanics of how networks are generated. Identifying key variables and generating a survey that was an appropriate length was a second challenge. Scaling back and focusing on the most essential questions is difficult in most survey designs; students reached out to a professional staff member at a North Carolina SWCD to pilot the survey and provide feedback. Finally, the contact strategy to get surveys to SWCD supervisors proved less successful than anticipated leading to disappointing response rates.

Results

Across interviews, faculty identified faculty-faculty interactions and collaborations as being central to their course experience. Student-faculty interactions were only mentioned 3 times, whereas faculty-faculty interactions and collaborations were mentioned 13 times collectively. Student-faculty collaboration was not identified as a theme throughout the interviews.

A lack of time necessary to complete all course objectives was mentioned by every interviewee. One interviewee stated: "…I think the class is trying to do too much in one semester. Teaching convergence and teaching research and, like, trying to sort of, like, teach phosphorus sustainability in 16 weeks is too much."

Students were often cited as an overwhelmingly positive influence on the course's success. Two interviewees noted that the level of student engagement and willingness to take on the uncertainty inherent in convergence projects was key to driving the course forward. The diversity of disciplines to which the

Table 3 Example quotes demonstrating the three habits of mind coded in interviews.

Habit of Mind	Quotes
Interdependence	"When I'm part of a group, I learn more rather than bringing things to the table, I want to learn because what you learn basically what helps your results to be ready for them to use so thats the biggest um skill I got out of it that you've got to listen, you've got to take note of what they are doing, what field they are in. Then when you're on your own, you can actually transcribe this to see how specific things fits into your own or something as simple at obtaining the results in the right format."
	"I mean, certainly in the the room that we spent in the classroom with the students, my focus was much more on trying to make explicit connections to other things that were going on in the class… because we did want the students to get that sense of what we're doing, even though it may be a smaller piece of the puzzle. It's amplified by connections to other, other team members or informing other projects."
Epistemic humility	"Even if I'm teaching, like a new class for the first time, I'm at least a day ahead of the class, you know, or like I, I know I prepped and I know what I'm going to present today or what we're going to learn about, this class, it was just a lot more open endedness. There was a lot less, preparation, I guess, like, there, you know, it often it was sort of real time trying to decipher information as the questions were coming up from students.So I guess in that regard, we spent more time, you know, grounding ourselves or, you know, not not necessarily having a curriculum or an answer to start from."
	"I prepared for the class not thinking about the needs of my discipline but a general need of the field and of my research rather than just focused on what I bring to the table, this wasn't the case. So in terms of how it shaped my teaching, it made me listen more, it made me listen more"
	"I definitely remember at, like some of my most vivid, positive memories of the RAMP class are conversations that happened faculty to faculty in front of students where we're connecting ideas across disciplines… the value that is embedded in showing folks, here's these two things that you don't think would really have all that much in common, but there's some deeper underlying experience that helps us sort of understand these processes in a, like in similar ways."
Co-creation of knowledge	"With what I have learned from the RAMP class and from convergence science, I know the first steps to take when I get my results. The first step would be engagement, stakeholder engagement. After stakeholder engagement, look into policy and regulations pertaining to trends that you have seen within your field so I think it did"
	"And, you know, if I'm going to continue doing this work in the future, I want to, you know, work with these stakeholders and use their expertise to help, drive what we're trying to answer, drive to figure out the questions that we want to ask or to try and get to that end goal of, increasing phosphorus sustainability."

students belong was also referenced as a contributing factor to the course's success.

The metrics by which faculty considered the course successful were the production of research outcomes and the degree to which students gained convergence research skills. Interviewees stated that few research outcome goals were met, often associated with the lack of time in the course. For example, one interviewee stated this about student expectations of the research outcomes: "there's no way in the course time allotted to do science and we're, we're pretending when we say there is and I don't know what needs to give there, but, I mean, I think there are great ways to use course time to get a model that looks like science and students get some of that flavor, or there's meaningful ways to take undergraduates and immerse them in science" In contrast, the interviewees referenced the student learning outcome of gaining convergence research skills as a successful aspect of the course with the same interviewee noting: "I think the transdisciplinary team was good for training students that you know, how problems could be addressed from different perspectives and possibly how, you know, maybe like, kind of like taking that into their research DNA at an early age, maybe it has outcomes that are meaningful".

Throughout the interviews conducted, the interviewees demonstrated individual evidence of having onboarded the three habits of mind: interdependence, epistemic humility, and co-creation of knowledge. Epistemic humility was demonstrated across all four interviews in three different ways: 1) recognition that answers to student questions are often not discipline-specific and must be formulated in realtime, 2) acknowledgement that multiple disciplines are needed to understand P sustainability in the context of its cycling in agricultural soils, and 3) appreciation that concepts from different disciplines are often related and can be simultaneously used to understand wicked problems (Table 3).

Interdependence and co-creation of knowledge were each demonstrated in three and two out of four interviews, respectively. Interviewees reported gaining skills in interdependence through exploring how their own projects relate to each other and making connections beyond their own field to broader issues of P sustainability. Co-creation of knowledge was primarily invoked in terms of the skills interviewees gained in stakeholder engagement and the process of incorporating stakeholders into their research (Table 3).

Discussion

This exploratory study suggests that the course structures implemented in the RAMP course can encourage faculty learning and skill development alongside students. The focus of the course on demonstrating and implementing integration along with students fostered probing and curious conversations in the classroom that would not have occurred otherwise, as noted by one interviewee: "I definitely remember at, like some of my most vivid, positive memories of the RAMP class are conversations that happened faculty to faculty in front of students where we're connecting ideas across disciplines" (Table 3). RAMP provided the opportunity and context for these interactions and collaborations. Subsequently, communication across disciplines was a prevalent theme. Interviewees referenced an increased ability to listen, acknowledge interconnectedness, and communicate research concepts to other faculty in different disciplines, all skills necessary for effective convergence research (Cravens et al. 2022; Bammer, 2013).

Faculty-faculty interactions in the presence of students were highlighted much more frequently than student-led discussions.Two possible explanations for this are: (1) Faculty-faculty interactions stood out more to faculty since they are not as common in a classroom setting or (2) Faculty tended to dominate discussion during class, leading to more faculty interactions. Sophomore-level students are very much developing their nascent discipline-specific knowledge, so it is easy for faculty to overshadow students during discussions. Convergence between disciplines is challenged when discipline-specific knowledge has not yet been imbued into the participants, as some disciplinary and is required to participate in convergence research (Fiore et al. 2019).

Challenges related to each student's inexperience could be compounded by the diversity of majors enrolled in the course, but when overcome, this diversity increases opportunities for convergence among the students and faculty (Klein, 1996). While their majors may not outwardly relate to their project, the students' content knowledge often brings new perspectives when discussing the larger context of the P wicked problem. Overall, diversity of student majors was cited as a positive contribution to the course learning outcomes, challenging faculty to practice epistemic humility and integrate multiple perspectives throughout their projects.

A paucity of time in the course exacerbated these challenges by limiting the ability of faculty and students to review necessary subject matter material, conduct research, and converge across projects over the course of the semester. Students were asked to engage in original research in a single semester with scant training and minimal prior experience. While faculty mentors offered broad project outlines that generally could be achieved by undergraduates, a deference toward student designed projects sometimes led to projects less likely to bear fruit. There also is potential for student-led projects to take faculty away from their core area of expertise, limiting the quality of mentorship that may be offered. Each of these considerations can slow the pace of research, further confounding the time limitations inherent to a one-semester research course.

Students were afforded limited time within select class periods to engage in research activities. A premium was placed on additional engagement outside of formal meetings, although improved organization to maximize extracurricular worktime is an area for future refinement. Faculty mentors were intentional in the choice of methodologies offered to each research group, striving to select techniques within the competency of undergraduates in their discipline. Nevertheless, the RAMP model offered additional challenges as students from diverse majors were asked to quickly gain proficiencies in these techniques before applying them towards research questions of their own formulation. Given the limited time frame of the course and the emphasis on gaining convergence research skills, the course would be improved by providing students with a more well-defined set of projects.

The cross-disciplinary representation of students on each research team, as well as frequent and heavily emphasized communication across teams served to facilitate research progress, while fostering the mannerisms and cultural proclivities likely to advance future convergence research. Within only a few weeks of research engagement, teams began to prepare final results for dissemination to the broader class. This accelerated timeline limited the extent of research production but favored communication and iterative cross-pollination between and within traditional disciplinary boundaries among project teams.

Time management is one of the most essential considerations with the RAMP course. In addition to conducting mentored research, students and faculty were asked to devote considerable time towards reflection, collaboration, and communication, fostering skills essential for convergent research. While meaningful in this regard, this skill development necessarily took precious time away from research activities. While research outcomes suffered due to this course structure, there is evidence for both student and faculty learning of convergence research competencies.

A survey taken of students from the Fall 2022 iteration of the RAMP course confirmed that students still retain convergence research skills and knowledge even a year after completing the course (Rickabaugh and Siegel, 2025). In their responses to the student survey and semi-structured interview questions, research participants

noted that the RAMP course instilled them with a heightened affinity for collaborative problem solving and a deeper understanding of how transdisciplinary strategies can be useful for addressing complex, multifaceted societal issues. Students also reported that as a result of completing the course, they feel more confident working with individuals from across disciplines (outside of their own).

The course was further impacted by the lack of cohesiveness across projects. While the projects focused on tackling a shared topic, P cycling in agricultural soil, there was no shared output or research goal. This was in part a result of the designed-in agency that students had over selecting their project directions, but one interviewee noted this as a weakness of the course: "But if we had some sort of overarching thread to keep the projects connected like that, it might be [cohesive]. It might lead to more meaningful interactions between the groups. And be a better example of interdisciplinary or transdisciplinary work." This suggests that cross-project convergence as envisioned by the design team was not meaningfully achieved, in that students and faculty became familiar with their own project goals and methods but did not necessarily experience a blending or integration of their work within the context of the larger phosphorus sustainability framework that could have been understood to connect all of the work together. This caused a fracturing of the course into individual construction of learning ecosystems comprised of project leads and their student teams (Lombardi et al. 2021). However, some success can be considered in that faculty were able to identify and name the lack of cohesion between projects, demonstrating a greater understanding of convergence research in practice.

It may be that the research projects offered within the class structure afforded a sandbox for the teaching of convergence skills, hopefully informing the perspective of participants for years to come. It is worth noting the difficulty of developing a culture of convergence has been identified as a barrier when trying to train even graduate students to address wicked problems (Kawa et al. 2021). The RAMP model is designed to help foster the intellectual culture and convergence competencies needed for current and future generations of scientists to embrace collaboration and convergence in their work, through the systematic development and practice of individual habits of mind. Emphasis on individual collaboration readiness is built as a foundation of the RAMP model in recognition that these skills are an essential building block of successful research teams (Hall et al. 2019).

These individual capacity advances are a critical stepping stone to collaboration readiness and team convergence capacity.

Conclusion

While new and evolving, elements of the Research-to-Action Multidisciplinary (RAMP) course are demonstrating to be effective for training faculty and undergraduate students in convergence research. By collectively addressing a single wicked problem through completing several group projects, they gain the meta-cognitive skills to integrate knowledge across disciplines. The RAMP model identifies some essential components for a convergence course structure: (1) ample opportunities for students and faculty to engage across projects, (2) frequent opportunities for individual reflection, (3) project themes of an appropriate scope, and (4) effective team teaching.

Those seeking to replicate this model should be aware of the many challenges to overcome as well. Institutional barriers to interdisciplinary team teaching can be bureaucratically challenging as well as sourcing the necessary funding for research projects. RAMP at Appalachian State was able to overcome these barriers by modifying current pathways and intentionally investing in roles to address the necessary integrative tasks to support the work. The incentives created by the shared funding opportunity of STEPS "greased the wheels" for this process. Typical course organizational challenges are compounded because many faculty have not team-taught in such a format. Assigning an instructor of record to handle tasks such as assignment creation, lecture scheduling, grading, and other organizational tasks is highly recommended.

Based on a preliminary, exploratory analysis of faculty interviews, this model provides the opportunity for faculty and student co-learning of convergence research skills. Through teaching this course, faculty gained cross-disciplinary communication skills and increased their proficiency in the habits of mind necessary to participate in convergence research. However, this learning mostly occurred through faculty interactions with one another, leaving students as primarily observers of the convergence process rather than active leaders. The course was successful in creating a culture of convergence among students and faculty, as evidenced by demonstration of individual capacities and awareness of convergence methods. While tangible research outcomes were not achieved in the short time-frame provided by this course, the adoption of metacognitive practices, awareness of convergence processes, and demonstration of the individual capacities in the form of habits of mind was achieved to seed future convergence experiences.

Data availability

Data sharing in this article is not feasible. Given the small sample size and that the names of interview participants are public knowledge, privacy could not be guaranteed upon release of the full interviews. Quotes in the article were chosen carefully to maintain confidentiality given these reasons.

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Author contributions

All authors contributed to the design and implementation of the course described in this manuscript. K.B. completed the data collection and analysis as well as the first draft of the manuscript with section additions from M.O., R.S., J.R. and M.H. All authors commented on the drafted manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

The interviews in this study were conducted in compliance with Appalachian State's Institutional Review Board Office and according to the principles of the Declaration of Helsinki. Exempt status was approved on July 9th, 2023, approval id: HS-25-27. Exempt status was granted based on the following criteria: (1) the research on instructional activities was conducted in an educational setting and are not likely to have adverse effects on student learning, and (2) sharing the results of the interviews posed little to no professional, personal, or financial risk to participants.

Informed consent

All interview participants were provided an information sheet about the research, how the data would be used (including publishing), and any risks the research may pose prior to their interview. The information sheet was sent to all participants on July 10th, 2023 along with the request to participate in the study. It was made clear that by signing up to be interviewed, participants consented to the use of their data in this manuscript.

Additional information

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