

Essay Title: Using Pathway Modeling to Evaluate and Improve Student-Centered Teaching Practices in Co-Taught College Science Courses

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Abstract

Student-centered teaching practices such as active learning continue to gain momentum in college science education. Many instructors committed to these innovative practices transform their classroom beyond the standard lecture. Nevertheless, widespread implementation of these practices is limited because the learning benefits for students are often attained through increased instructional complexity to which many instructors cannot commit. When co-instructors are teaching the course, the level of commitment to building a student-centered classroom may be even more profound. For these reasons, new tools are needed to help instructors and co-instructors plan, organize, evaluate, and communicate their classroom innovations. Pathway modeling is a tool with potential to fill this gap. Unlike curriculum mapping -- which identifies academic content gaps, redundancies, and misalignments by examining a series of courses within a plan of study -- course pathway modeling creates a visual map of a single course and reveals how teaching practices influence short-, mid-, and long-term student learning outcomes. This essay demonstrates how course pathway modeling can help co-instructors better represent the complexity of student-centered teaching practices. We include guides for creating course pathway models and discuss how this approach offers the potential to improve curricular design, course evaluation, student assessment, and communication between co-instructors.

Introduction

Student-centered teaching strategies such as active learning, formative assessment, and inclusivity are implemented less often in college science classrooms than has been anticipated; lecturing still dominates despite over a decade of investment in teaching reforms (Stains et al., 2018). While many science faculty are persuaded that teaching in a more active, engaging, and inclusive way is needed, there are many reasons why sustained change has lagged behind their recognition and desire for improvement. For example, the perceived barriers to restructuring an entire course, or even aspects of it, may feel overwhelming to faculty who have other academic obligations competing for their time and effort (Henderson & Dancy, 2007). Also, students sometimes resist classroom practices that require increased participation (Seidel & Tanner, 2013). These challenges can be compounded when course delivery requires buy-in and coordination from more than one instructor, as in co-taught courses (Morelock et al., 2017).

Co-teaching takes many forms. In some cases, two or more instructors collaborate on the design and execution of a course. In other situations, instructors collaborate on course design to a certain degree and then independently teach different sections. Previous work has shown that it is

important to not only establish and maintain a strong communicative relationship, but also to conduct joint planning in a co-teaching setting (Letterman & Dugan, 2004; Morelock et al., 2017; Quinlan, 1998). Should any of the co-instructors decide to implement more student-centered pedagogies, the course complexity increases. Consequently, teaching in this way presents a new challenge for co-instructors to maintain consistency and clear communication within their course.

In the early stages of transitioning to more engaging teaching practices, instructors often rely on traditional assessment measures such as student feedback on end-of-course evaluations, quiz and exam grades, and other indicators like attendance or course participation (Garfield, 1994). Unfortunately, these may not be precise enough to gauge the success of their changes. Faculty may also fear the consequences of these measures stagnating (or worse, declining) and curtail their transformation efforts (Terenzini, 1989). This situation can be further exacerbated when co-teaching is involved, as disparities in experience, goals, and classroom challenges can lead to frustration or conflict. In order for instructors to develop the skills and confidence to teach in engaging ways, their reflection and evaluation practices must co-evolve alongside pedagogy (Darling-Hammond & Snyder, 2000). At a minimum, instructors must obtain a more complete picture of the overall student experience and find ways to represent the inherent complexities associated with evidence-based teaching (EBT) practices.

A meta-analysis by Henderson and colleagues argued that in order to facilitate the adoption of EBT practices, in addition to focusing on “prescribed” activities such as professional training, successful transformations can also benefit from “emergent” reflective practices and vision sharing among stakeholders (Henderson et al., 2011). This can be particularly important for a co-taught course. Yet, emergent reflective practices and vision sharing may be difficult to implement if co-instructors lack a way to “see” the inner workings of their course and respective teaching practices and communicate this to other course stakeholders. Once instructors visualize their course, it is easier for a range of stakeholders, including other instructors or department heads, to identify the resources and supports needed to implement the desired practices (Reeves et al., 2020).

From the program evaluation literature, we introduce a framework to better “see” the inherent complexity and the inner workings of how a science course functions -- prior to, during, and after a given semester -- as a novel way to monitor progress and address challenges that inevitably arise when co-teaching. Adopted from a systems approach to complex program evaluation (see Urban & Trochim, 2009), course pathway models are visual maps created to help co-instructors and various stakeholders of a course understand the multiple, interrelated priorities and components of a course. A pathway model is one part of a larger systems evaluation protocol which thoroughly describes a systems approach to evaluation (see CORE, 2016; Urban & Trochim, 2009).

Like the traditional logic model, the course pathway model helps stakeholders identify the short-, mid-, and long-term student outcomes that contribute to the overall course goal. Pathway models go a step beyond the traditional logic model (see Millar et al., 2001) by considering the multiple “systems” -- e.g., stakeholders such as the instructor, the students, the teaching assistants (TAs), the department, the institution -- in which a program (or here, a course) resides (Urban & Trochim, 2009). The course pathway model that we propose is not derived from a single logic model; rather, it aims to integrate a network of logic models that describe the larger system in which a college science course exists. For example, a logic model of instructional practices created by the instructor can be visually linked to a logic model of student assessment. Across logic models, the intended outcomes of each model can then be integrated and made more visual via the pathway model approach (CORE, 2016).

To summarize, since the ideas surrounding pathway modeling have been proposed in the program evaluation literature as a way to promote critical reflection (Buckley et al., 2015), the course pathway model could similarly function to improve course design and evaluation. Once a course is visually mapped in this way, co-instructors will have a better opportunity to “see” where the important learning components are centered (referred to as “hubs”) and then identify measures to assess intended short-, mid-, and, potentially, long-term course outcomes (see CORE, 2016; Urban & Trochim, 2009). We have found that even in an established course, pathway modeling gives co-instructors a concrete way to identify new opportunities to enhance student learning or clarify obstacles that manifest as they transition out of their comfort zone into a new pedagogy.

What follows is a visualization and description of our approach to the course modeling process, its affordances, and its potential benefits to instructors and evaluation teams interested in assessing the effectiveness of teaching innovations.

Using a course modeling approach for design and assessment

Creating a course pathway model generally involves initial preparation, model creation, model revision with key stakeholders, and model simplification. Applying this process iteratively allows for feedback loops to further connect intended course goals with course elements. We applied these procedures within a science courses that we often co-teach, which features active learning and other forms of student-centered teaching. In developing our course pathway models, we prioritized:

1. Using clear and concise definitions of course goals that were aligned among instructors.
2. Incorporating feedback from multiple stakeholders including faculty, teaching assistants, students, and instructors of upper-level courses to drive model evolution (see Supplemental Table 1).
3. Viewing the course within a complex environment (e.g., student prior knowledge variability, diversity of attitudes, physical classroom spaces, curricular requirements, etc.) (see Supplemental Table 2).
4. Considering learning as a process, not an endpoint (e.g., final grades).
5. Creating an actionable, visual product that could be analyzed and implemented even while the course is in progress.

Next are specific considerations that we identified to assist with our model development process (see Figure 1) and some examples from our course.

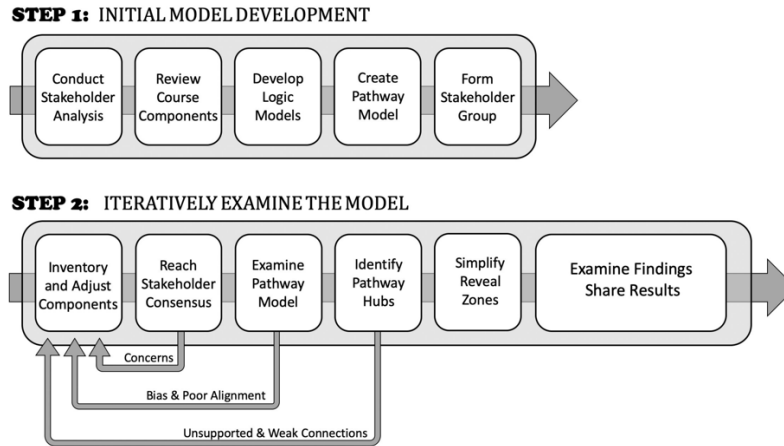


Figure 1. Course Modeling General Approach. Modeling steps are adapted from System Evaluation Protocol (SEP) for course modeling purposes.

The first step of this process is to conduct an initial review of the course that identifies as many elements of the course ecosystem as possible (see Supplemental Materials for more detailed sub-steps). Essentially, this review should comprehensively capture the context, resources, and activities for a given course. Based upon our experience, we created an example template to help co-instructors identify the initial scope and focus (see Supplemental Table 3). Iterative examinations can increase or decrease complexity from this initial starting point. Similarly, when thinking about which course activities to include in the model, instructors should consider activities that happen within the classroom (e.g., classroom polling), as well as asynchronous components (e.g., homework, office hours, studying). We have created a worksheet to help instructors brainstorm these activities (see Supplemental Table 4).

Once this information has been collected, the next step is to have a course model builder, usually an instructor, enter this information into a standard logic model framework to identify inputs, activities, outputs, and outcomes (Cooksy et al., 2001). As an example, Figure 2 shows how a simple course activity supporting short- and medium-term outcomes from the logic model would be displayed in a pathway model.

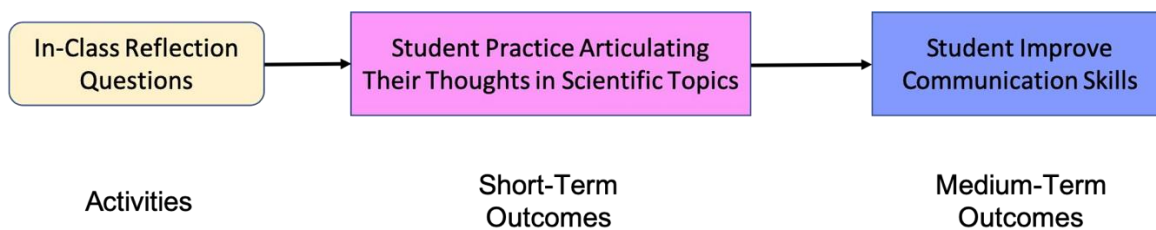


Figure 2. Pathway Model for an Anatomy and Physiology Course. Cream boxes represent class activities, while pink, purple and green boxes represent short-term, medium-term, and green boxes represent long-term outcomes, respectively.

As previously mentioned, it is likely that multiple logic models are needed to represent the complexity of the environment within which the course resides. The next step is where the course pathway model diverges from standard logic modeling. Currently, the Evaluation Netway

(www.evaluationnetway.org) and Mural (www.mural.co) are technological tools for modelers to integrate logic models and make connections between them to create a visual representation of their course.

The newly created course pathway model can undergo iterative examination through a series of reviews conducted by the model builder and, if possible, other interested stakeholders. The visualization generated from the previous step supports assessment of the overall breadth of the model and the alignment between course components. To ensure that alignment has been achieved, this step can benefit from a working group that includes other stakeholders such as students, colleagues, and/or evaluators in addition to the course instructors. The working group should examine if the course activities, resources, and supports provided by the instructors are sufficient to reach the course goals. For example, does the inclusion of diverse undergraduate mentors create a sense of community that might ultimately instill a sense of belonging in science? Importantly, the working group should also identify unsupported assumptions made by the primary model builder when establishing the logical relationships used by the model. For example, one question may be: does the implementation of an activity guarantee improved learning even if student engagement is minimal, or class attendance is low? When the concerns that arise from this step have been adequately addressed, a final course model is created that provides a comprehensive view of the course.

The finished model will likely be complex in order to reflect the many components of a student-centered course. To communicate the main model findings effectively for a broader group of stakeholders, we recommend simplifying the model into “zones” as a final step (see Reeves et al., 2020). A simplified model is not intended to replace the comprehensive model generated in the previous step, but rather to exist in parallel and provide an alternate, more digestible view. An instructor could use a simplified model as a visual aid to facilitate TA training, convey the logistics of their course to another instructor teaching a pre- or co-requisite course, or advocate for resources in their course.

Example: Modeling to Improve an Anatomy and Physiology Course

Context and participants for the adoption of the course pathway model

In 2009 and 2015, two departmental colleagues who teach Anatomy and Physiology at the University of Connecticut participated in the Summer Institutes on Scientific Teaching (SI), a national instructor training program that seeks to increase the use of “scientific teaching” in undergraduate STEM classrooms (Summer Institutes on Scientific Teaching). “Scientific teaching” is a term used to describe a student-centered pedagogical approach that incorporates active learning, formative assessment, and inclusive teaching practices as core elements (Handelsman et al., 2007). These practices are known as Evidence-Based Teaching (EBT) strategies and EBT reflects the spirit of scientific research being based on existing evidence from peer-reviewed literature. After the SI training, one of the instructors made a substantial effort to implement EBT practices in her co-taught two-semester Anatomy and Physiology course offered to biology majors. Although student participation and feedback were generally positive after increasing the use of EBT in the course, student exam performance did not significantly increase compared to previous years. After sharing these findings, evaluators affiliated with the SI introduced the instructor to pathway modeling as a way to better understand her course’s inner structure and outcomes. Her departmental colleague who also participated in the SI became a collaborator in the pathway modeling project because he wanted to expand his pedagogical toolbox. The colleague co-teaches a section of the course in the summer and a related course for non-majors during the academic year. As such, this manuscript takes an inclusive view of co-teaching, recognizing that although the instructors who undertook pathway modeling co-teach different sections of the same course, they both benefitted from the vision sharing and course

goal alignment process spurred by pathway modeling. They relayed their insights to their teaching partners and departmental colleagues to facilitate discussion and standardize implementation of course innovations resulting from the model.

Initial pathway model construction

Once the instructors became familiar with the overall process and visualization tools, they created the initial course model, a process that took about 5-7 hours in total to draft, spread out over several 1-2 hour meetings focused on brainstorming and model refinement. An evaluator familiar with the modeling process periodically reviewed the overall flow of the course pathway model with them. Through these review meetings, they realized that the model did not capture all components of the course. For example, the contributions of teaching assistants were absent because they had focused only on instructor practices. They then revised the model and shared it with other stakeholders (e.g., teaching assistants during their weekly meetings). The expanded working group used the model in addition to student evaluation and assessment data to reflect on miscommunications and assumptions that were made designing the course. The co-instructors set up a one-hour standing meeting throughout the semester, making the overall time investment up to this point approximately 15 hours. Using the model, the instructors made several important course improvements, and the model was further revised. Eventually, revisions reached a plateau as the instructors worked to optimize the course, but they realized it can continue to evolve and be revisited as needed. The full model is provided in Supplemental Figure 1 and a suggested list of stakeholders and their appropriate roles in the process is provided in Figure 3.

Suggested Stakeholder	Suggested Role	Suggested Recruitment Strategy	Approximate Time Investment	Motivation to Participate
Co-instructor	Primary model builder	Intrinsic motivation	10-15 hours	Improved efficiency in course development, revision, and assessment; improved communication and alignment between stakeholders
Co-instructor	Secondary model builder	Intrinsic motivation, collegiality	8-10 hours	Improved efficiency in course development, revision, and assessment; improved communication and alignment between stakeholders.
Graduate TA	Working group	Requirement of position	1-2 hours	Better understanding of teaching, professional development, improved classroom experience
Undergraduate student	Working group/benefactor	Extra credit or independent study opportunity, announcement in class or via learning management system	1-2 hours	Better understanding of course and improved context for curriculum
Department head/administrator	Benefactor	Internal/external department review, PTR process, departmental retreat	<30 minutes	Reporting, resource allocation, department advocacy

Figure 3. Potential Stakeholders. Stakeholder groups will vary depending on the type of course being modeled.

As illustrated in the full pathway model (see Supplemental Figure 1), the model has a general left to right flow, with course activities linked to short-term outcomes (e.g., explicit discussion of scientific teaching leads to students learning about metacognition (Tanner, 2012)). Each short-term outcome must lead to either another short-term outcome or to medium-term outcome(s): e.g., students learning about metacognition leads to students reviewing their learning process. As a rule, a short-term outcome cannot directly connect with a long-term outcome (see CORE, 2016; Urban & Trochim, 2009). In turn, medium-term outcomes contribute to other medium-term outcomes or long-term outcomes (e.g., students metacognitively reviewing their learning process leads to improved student learning). In Figure 2 we provide a visual from the model that

demonstrates these relationships linearly. Importantly, when engaging in this part of the mapping process, be judicious so as not to make too few or too many connections.

Due to the overlapping and highly interconnected nature of pathway model's boxes and arrows, there will likely be *convergence* and *divergence* in any given model. *Convergence* occurs when multiple activities lead to the same outcome. For example, there are multiple activities that support the short-term outcome, "students practice articulating their thoughts on science topics." Similarly, multiple short-term outcomes contribute to the same medium-term outcome, such as, "students improve study skills." On the other hand, *divergence* occurs when one activity leads to multiple outcomes. For instance, the box titled "students perceive that classroom discussion is normal" leads to multiple medium-term outcomes, including "students learn challenging topics" and "students ask questions in multiple settings" (e.g., in lecture versus lab).

Furthermore, certain outcomes are important intermediates that serve as "hubs" (Urban & Trochim, 2009). The pathway model visualization allows for easy identification and analysis of these key measures and instructional milestones. To qualify as a "hub" in the map, the instructors decided that there needed to be at least four inputs and one output. The criterion for a hub is somewhat arbitrary because it will depend on the overall complexity of the model. The key is to identify intermediates that serve important outcomes within the model and examine how they are supported. Using this criterion, several important hubs were identified in the model, including: students ask questions in multiple settings; students receive formative feedback from their instructor on an ongoing basis; TAs revise and improve their lesson plans and teaching methods; and, improved student learning. In order to facilitate further discussion of the model below, the instructors focused on these areas independently. In Figure 4, we provide an example showing some of the inputs into the "improved student learning" hub, but readers can refer to the full model in Supplemental Figure 1.

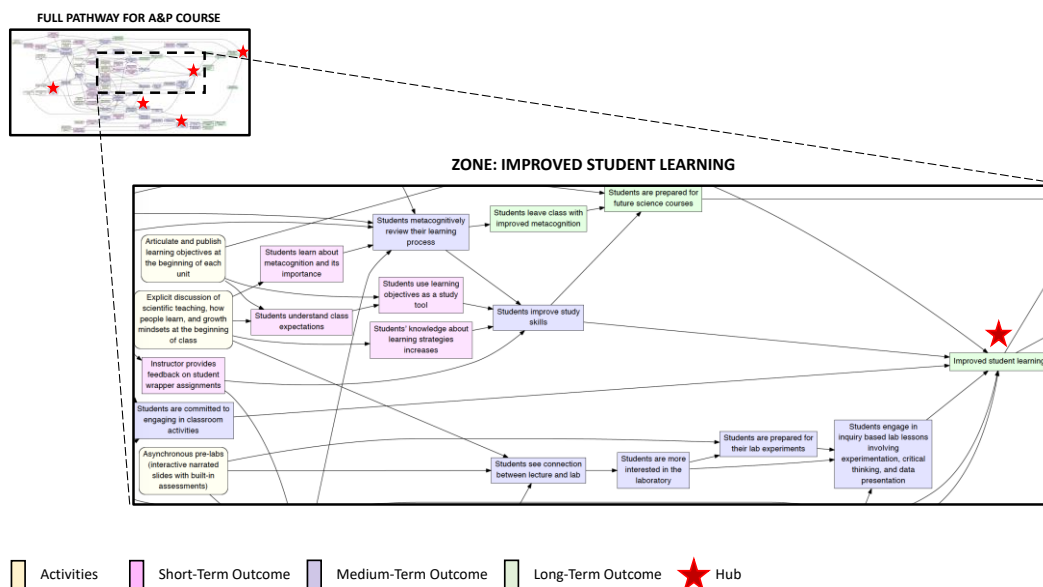


Figure 4. Identification of Key Hubs. Key outcome hubs were identified based on the number of arrows connected to a particular outcome. Cream boxes represent class activities, while pink, purple and green boxes represent short-term, medium-term, and long-term outcomes, respectively.

Prepare the model for broader communication

Before discussing the model with other stakeholders and receiving their input, the instructors “cleaned-up” and “simplified” the model to illustrate the major takeaways. Figure 5 describes this process of iterative examination and simplification. They worked together on this task which took an additional 2 hours. The time investment is likely to correlate with the quantity and complexity of model inputs. This illustration broadly captures three emerging themes from the course pathway model – student motivation, engagement, and support -- that the literature suggests can support the ultimate long-term goal of *improved student learning*. *Motivation*, here defined as a student’s desire to participate in the learning process (Lumsden, 1994), improves student engagement (Pintrich, 1991); likewise, a learning community can strengthen a student’s sense of belonging, further improving motivation and engagement, and can further lead to more sustained college student persistence in the sciences (Graham et al., 2013). These elements -- motivation, engagement, and support from the learning community -- are highly interconnected and the mapping process allowed us to see the details of how each can be achieved (Zumbrunn et al., 2014). For example, when considering the third pathway of *support* from the learning community, an important component is the contribution of TAs. Building the pathway model lent the instructors the major insight that the strategic involvement of TAs required appropriate training and a shared vision beyond what had originally been anticipated.

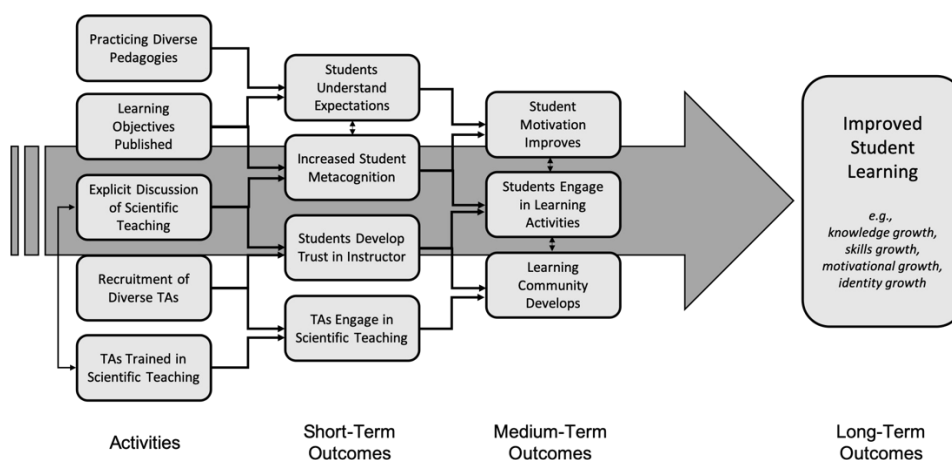


Figure 5. Simplified Course Pathway Model. Themes of activities, short-term, medium-term, and long-term outcomes are summarized and presented in columns.

Utilize the pathway model to improve the course

When examining the pathways, it became clear that an existing assumption was that once the instructors provided students with engaging activities, students would feel more motivated which would lead to improved learning (Freeman et al., 2014). Through the course pathway model, however, they realized that this assumption was flawed since many students do not see the connection between class activities and their learning and may feel uncomfortable participating in group work (see Cavanagh et al., 2016). As a result, they altered the course (and the pathway model) by strengthening and improving the following three components of the course.

The first course improvement made was based on the realization that a deeper, more intentional focus on student buy-in to scientific teaching practices was needed in order to promote student engagement (Cavanagh et al., 2016; Finelli et al., 2018). Deliberative practices, such as

discussing the cognitive science of learning with students, became a critical focus for the instructors (Seidel & Tanner, 2013). The instructors determined that in order for students to feel more motivated to engage with “evidence-based” learning activities, instructors must provide a convincing and transparent rationale for why certain course activities – like group work -- are required (Bacon et al., 1999; Felder, 2011; Strobel & van Barneveld, 2009; Tharayil et al., 2018; Straits & Wilke, 2003). As a result, the co-instructors developed new activities that focused on scientific teaching training for students and TAs and included these activities in the pathway model.

The second course improvement made was based upon the realization that the misalignment of assessment practices and the short-, medium-, and long-term goals identified in the course pathway model could lead to a lack of motivation among students (Bentley et al., 2011; Donohue & Richards, 2009). By working together to examine the model, the co-instructors realized that they needed to align their teaching practices with student assessment. For example, they discovered that despite their shared vision for students to work together in class, they differed in their approaches to achieve this end. This caused confusion and disinterest among students, and it also confounded grading. As a result, they introduced new components to their class and adjusted the summative assessment scheme to better reflect their mutual course activities and goals. For example, team-based learning and participation are now graded components of the course whereas before student grades were determined largely by exam performance.

The third course improvement made was based on several new insights about the long-term outcomes identified in the course pathway model. For example, in order to improve student learning in meaningful ways: i) students need to finish the course with skills to succeed in future science courses (see Brewer & Smith, 2011); ii) students need to gain confidence learning challenging topics (Ballen et al., 2017); and, iii) students need to find ways to identify themselves as members of the broader science community (Carlone & Johnson, 2007; Trujillo & Tanner, 2014). Building “science identity” was consistently an important course goal and yet, through course pathway modeling, the co-instructors identified that there was no support for this goal in their current course structure.

One reason that students may not feel they belong in a course is because they don't think that they contribute to class activities (Finelli et al., 2018; Kearney et al., 1991; Seidel & Tanner, 2013;). Therefore, the instructors created opportunities for all students to voice their opinions, provide suggestions, and receive feedback on how their suggestions were incorporated. They now explicitly discuss in class how important it is to receive feedback from all students regardless of where they are in the learning process. Additionally, developing a science identity is particularly challenging for underrepresented minority students (URMs) (Chemers et al., 2011; Hurtado et al., 2010). In subsequent semesters, there was a renewed emphasis on building students' science identity. The co-instructors have, for example, focused on more consciously recruiting URMs to become undergraduate teaching assistants to facilitate learning and motivate other URMs through near-peer interactions and mentoring (Strayhorn, 2010).

Discussion

Science courses exist within complex systems, and course pathway models represent their complexity by integrating a network of short-, mid-, and long-term outcomes across contexts and stakeholders. The goal is for the instructor or co-instructors to better “see” interrelated aspects of their course. The unique feature of a college science course pathway model is that it is a graphical representation of the instructional complexity between activities and outcomes that highlights how

a course seeks to achieve its goals. It provides an invaluable foundation for making sound improvements or evaluation decisions (see Urban & Trochim, 2009).

Although instructors can create valuable course pathway models independently, we have benefitted from collaborating with evaluators. In particular, evaluators helped the instructors expand their model to include motivational components, and provided a framework to explain the steps that should be followed to achieve the desired outcomes of active learning. Instructors working independently would benefit from possessing a working knowledge of common educational terms and logic models before embarking on this process (see Millar et al., 2001; Miller & Tanner, 2015). Guidance in these areas may be sought from on-campus centers for teaching and learning, if available. In order to make the process of model building feasible for a novice user, we distilled some key considerations into the supplemental worksheets, recognizing that some instructors will not be able to work with an evaluator (see Supplemental Materials). If an instructor seeks more resources on pathway modeling, we suggest browsing the open-access Systems Evaluation Protocol (CORE, 2016) and other resources provided in Supplemental Table 5.

We encourage using the course pathway model because it provides many benefits to instructors. First, the course pathway model increases efficiency in curriculum review and redesign. The Vision and Change movement (Brewer & Smith, 2011) has transformed many college science courses by encouraging the adoption of backward design, i.e., a more goal-oriented way to evaluate and redesign science courses. As Henderson and his colleagues have suggested, it is important to include “emergent” reflective practices and vision sharing among stakeholders, and course modeling facilitates this process (Henderson et al., 2011). For example, in reviewing the course through the perspectives of building a pathway model, the instructors identified several elements that are important for student success and developed new ways to reinforce them. This would have been far less obvious without the course pathway model as a reference point. In particular, by constructing and reviewing the course pathway model with stakeholders, the instructors gained insights that helped them to: i) address student misconceptions; ii) promote student-instructor interactions; and, iii) engage students more in the learning process.

Course pathway modeling also improved communication among stakeholder groups. Among college science educators, there has been renewed discussion on teaching effectiveness as well as increased emphasis on EBT. As a result, there is a growing realization that institutional culture and student commitment to EBT are critical elements of STEM education transformation (Henderson et al., 2011). Developing a shared vision among all stakeholders (e.g., instructors, administrators, students) will advance EBT efforts at a departmental and institutional level. Nevertheless, it can be difficult for each stakeholder group to communicate what they do in a systematic and substantive way to other stakeholders. Course pathway modeling provides a visual tool to facilitate this dialogue, particularly with regard to course goals and their implementation. Instructors may already have a logic model for their course and, if so, they should focus on the columns for “activities” and “outcomes” to think more deeply about additional logic models across the various systems within which the course resides. They can then work to make connections in a course pathway model that link activities and outcomes within the system.

Most importantly, the course model improves communication among co-instructors. Many science courses are co-taught by two or more instructors. Although many teaching partners frequently discuss various components of a course, it is rare for them to share their own visions of the course in a systematic and comprehensive way. Moreover, there may be a disconnect between what instructors intend do in class and what they actually do. One of the most direct benefits of creating a course pathway model is to clarify terms and practices used differently by different instructors.

The model is a tool that enables the sharing and discussion of ideas, merging of visions, and unification of instructor practices. In many cases, the course pathway model can be used to justify class activities by illustrating how they fit into overall learning goals. The instructors consider formative student feedback important for student learning; however, they implemented different strategies to collect and respond to it. For example, one instructor relied heavily on clicker questions and other active learning strategies, whereas the other instructor preferred to solicit verbal feedback from students in class, during office hours, and online through the course's learning management system. By building the course pathway model, the co-instructors became aware of each other's practices which promoted discussions that would not have otherwise happened.

Course pathway modeling also allows co-instructors to identify when certain course elements are missing or only sporadically present because not all instructors are implementing them or are in agreement about their importance. For example, despite the co-instructors' shared vision to increase diversity and representation in their course, they did not specifically recruit undergraduate teaching assistants from diverse backgrounds when launching an undergraduate teaching assistant program. The visual aid provided by the pathway model highlighted that this goal was largely unsupported, since we did not adequately account for inclusivity. Moreover, modeling allowed the instructors to work together to create multiple ways to ensure these key "hubs" were supported adequately, even if different instructors are teaching different class sessions, or different instructors are teaching different lesson units.

Given how pathway modeling has been applied in the evaluation literature as a method to better understand a program's design (Urban & Trochim, 2009), we propose that there is similar potential for pathway modeling to improve course design and evaluation. The pathway model can bridge the conversations between instructors and science education researchers/evaluators (e.g., clarify terminologies, explain practices). Perhaps more importantly, even for experienced evaluators, a holistic and comprehensive course map can facilitate the identification of various theoretical frameworks (i.e., motivation, critical thinking skills development) to inform the selection of measures to capture and explain the mechanisms underlying the observed teaching practices. For example, one area of the course model may focus on activities or outcomes best described through learning theories, while other areas might focus on student identity building, faculty development, TA training, or institutional support. The course map considers the complex ecosystem and life cycle of the course, and is capable of capturing various inputs to the system.

Once completed and simplified, the course pathway model may provide additional benefits for a variety of stakeholders. For students, a simplified course model, in addition to a traditional syllabus, could provide them with a clear roadmap of how learning activities will contribute to their success in the course. For instructors, the course model provides a way to justify resource allocation to administrators by visualizing impressive course features and desired outcomes. For administrators, the course model is a comprehensive way to identify or reward innovative teaching methods to maximize program effectiveness. In an early iteration of the model, nearly all of the components were instructor-focused. Following discussion within the expanded working group, the newest iteration of the course map demonstrates how multiple stakeholders make valuable contributions to the course goals. The instructors use this in dialogue with their undergraduate teaching assistants to generate enthusiasm around teaching, and with their undergraduate students to help them understand instructors' vision for their success in the course.

Limitations

There are several limitations to the present work. Although qualitative and anecdotal feedback provided by course evaluations has been positive, we have not yet evaluated how the course changes spurred by pathway modeling have impacted students in our co-taught class. While the education literature suggests that there are inherent benefits to improving student motivation, engagement, and belonging, more formal and targeted analysis of student outcomes is needed. While course pathway modeling by itself does not automatically improve student outcomes, vision sharing can help co-instructors communicate and realize their mutual course goals, whatever they may be. To our knowledge, however, there are no published examples of course pathway modeling in college sciences courses. Without additional adoption, it is still an open question whether the benefits we observed can be extended to other courses. Despite these limitations, the course pathway model has created an opportunity to make systematic changes to a co-taught Anatomy and Physiology course. It has also given instructors and evaluators a new perspective through which to evaluate those changes.

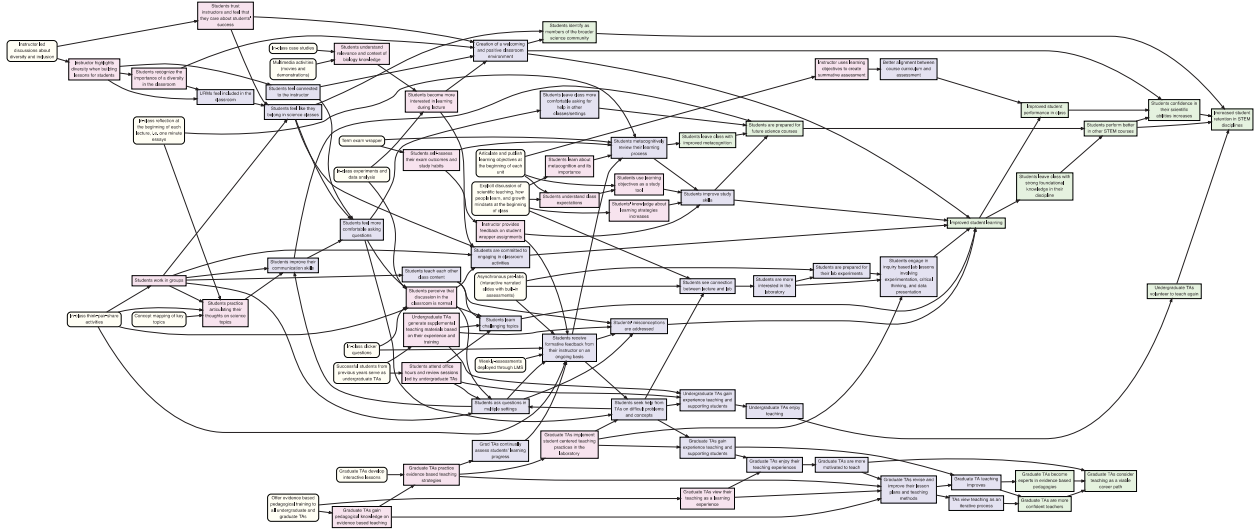
Conclusion

Pathway models have been used to identify research questions and develop evaluation plans for large-scale, complex educational programs. Here, we broaden the application of this approach to the development and evaluation of co-taught college science courses. This is not to say that other course evaluation methods should be replaced by course pathway modeling. Rather we suggest that reflecting on a visual representation of the complex environment within which a course exists -- created from a collaboration of instructors, evaluators, and students -- can shed light on course elements that might otherwise go unnoticed. From this perspective, course pathway modeling is an approach to help those interested in advancing course evaluation and assessment by providing a visual tool to identify measures and outcomes of primary interest. In this case, instructors use course mapping to identify and prioritize areas for improving teaching. This new addition to the college science course evaluation toolbox offers co-instructors and discipline-based education researchers a medium to evaluate courses in a novel way. Instead of just measuring the learning outcomes, the course modeling approach facilitates a rich and robust experience for all stakeholders by holistically monitoring the teaching process, the motivations behind it, and potential confounding factors. As more institutions look for new ways to evaluate teaching, it is our hope that the course pathway model approach can contribute to this national initiative.

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Supplemental Figure 1



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