Supplemental Materials

Course Pathway Modeling Procedures

Step 1: Prepare to Model by Conducting an Initial Review of the Course

A systems perspective considers the environment in which the course resides and its maturity. The first step of course pathway modeling involves preparing for the modeling process.

Step 1a: Stakeholder Analysis: Consider the Different Perspectives on Course

Stakeholders are defined as all people associated with the course in any capacity. In a college science course, stakeholders include instructors, students, teaching assistants (TAs), administrators, departmental colleagues, parents, and future employers of students. This step of creating a comprehensive list of stakeholders is necessary to ensure that instructors are not just teaching content that they themselves believe is important, but also consider the skills, attitudes, motivations, and perceptions that are valuable to others.

Step 1b: Articulate Course Short-, Medium-, and Long-term Outcomes

When constructing a course model, it is important to identify and articulate short-, medium-, and long-term outcomes of the course. Although there is flexibility in determining how an outcome might fit into a stage, framing outcomes at different stages allow the instructors to build in checkpoints for the anticipated learning progression. We consider the short-term outcomes as those that can be achieved at each module, class period, or sometimes at the conclusion of a class activity. We consider medium-term outcomes as those that can be achieved by the end of the course. That could include a higher level of student comprehension of course content or higher student retention rates. The ultimate and long-lasting outcomes for a course should be considered as long-term outcomes. These might include a student's increased desire to persist in STEM or increased ability and confidence in handling quantitative problems. It is worth noting that there might be overlapping among short-, medium-, and long-term outcomes, as some transient outcomes can turn into significant and long-lasting impacts.

Step 1c: Course Review: Consider the Existing Components of a Course

Taking an inventory of the existing elements within a course provides an initial overview of course structure, teaching practices, assessment strategies, peripheral supporting structures, and how they are perceived to support the important teaching goals identified in Step 1a (see above).

Step 1d: Determine What to Include in the Model Based on the Model's Purpose

Depending on the purpose of the course modeling project, decisions need to be made about what information should be included in the model. For example, if the purpose of course modeling is to implement course evaluation and redesign, input from students may be necessary to gain a better understanding of how students interact with course activities. However, if the purpose of modeling is to communicate with department heads about course goals and structure, input from students may not be necessary.

Step 2: Create the Course Model

The goal of this step is to generate a visual representation of a course that captures the course context, resources, and activities, and relates them to short-, medium-, and long-term outcomes.

Step 2a: Develop a Logic Model: Identify Relationships Between the Resources, Activities, Outputs, and the Outcomes of a Course

The first step is to generate an initial logic model that integrates course short-, medium-, and long-term outcomes. As previously described, short-term outcomes should be logically connected to activities involved in the course. Medium-term outcomes tend to be follow-up effects on participants, and are often deeper and more sustained changes in comparison to short-term outcomes. Long-term outcomes describe the ultimate, big picture effects that result from the medium-term outcomes. For example, a short-term outcome (e.g., *students discussing primary literature in class*), logically leads to a medium-term outcome (e.g., *students developing analytical skills based upon several discussions of the literature*), and ultimately leads to a long-term outcome (e.g., *students gaining the ability to assess the credibility of the new information*). Sometimes, a short-term outcome can connect to multiple medium-term outcomes (e.g., discussing primary literature in class may also improve interpersonal skills). Likewise, a medium-term outcome may be achieved through multiple short-term outcomes (e.g., analytical skills can also be developed when students participate in an inquiry-based laboratory).

Step 2b: Transition to a Pathway Model: Visualize the Connections Between Components

Since courses are complex, making sense of the logical expressions described above can be challenging. However, when the activities and outcomes (short-, medium-, and long-term) are identified and connected, a pathway model emerges. Specifically, a pathway model is a visualization of all of the logical inputs described in Step 3 (see below). Software, such as, the *Evaluation Netway* (https://core.human.cornell.edu/research/systems/netway.cfm) provides a straightforward way to enter and connect them and create a visual presentation. It clarifies relationships between course components and program outcomes, and provides an informative but concise picture of how the model builder believes the course operates. More importantly, the pathway model has the potential to highlight opportunities for course improvement. Ultimately, a course pathway model combines the vision of the course instructors with the existing components of a course.

Step 3: Iteratively Examine the Course Model

The created course model needs to be iteratively reviewed and the primary visualization tool generated in Step 2b is helpful to assess the breadth and alignment of the course components. This step usually involves the working group considering how course activities and resources support the course goals. For example, does having undergraduate mentors from diverse backgrounds instill a sense of belonging among underrepresented minority science students? Importantly, the working group also identifies unsupported assumptions made by the primary model builder when establishing the logical relationships in the model. For example, does the implementation of an activity guarantee a learning gain even if student engagement or attendance is low? These areas of further refinement can be identified using the procedure described in the following sub-steps.

Step 3a: Form a Reviewer Group: Bring Together Stakeholders

After completing the initial course model, a working group should be composed, at a minimum, of the course instructors and evaluators. Ideally, the working group would include representatives of all stakeholder groups (e.g., students, administrators, TAs). The working group examines the preliminary model more closely using the System Evaluation Protocol (SEP). This secondary check reduces bias, improves the logical relationships displayed in the model, and results in a more refined pathway course model (see Supplementary Figure 1 for the full pathway model).

Step 3b: Inventory All Course Components and Reach Consensus on Their Relative Importance and Representation in the Model

The purpose of this initial examination is to confirm that the components of the course are represented accurately and free of bias by the model builder (see Table 1 for examples of initial examination questions).

Table 1: Suggested Discussion Prompts for Working Group

Focus Area	Sample Questions:
Inventory Course Components	**Does the model reflect the overall vision of the course?** Are all goals identified and articulated in the model? Are all stakeholders' concerns represented?
Bias Checks	**Are all connections reasonable?** Do instructional practices align with course goals? Do the course structures align with course goals? Are there activities that support multiple goals? Is the timeline for outcomes reasonable? *(e.g., the amount of time it takes a student to effectively read a graph is less than the time required to gain the skills necessary to produce a graph, so the former may be a short-term outcome whereas the latter would likely be a medium-term outcome)*

Step 3c: Identify Key Hubs in the Pathway Model

In any course model there are inevitably some paths that are more important than others, since some outcomes are more central to the course (see CORE, 2016). For example, are there any long-term goals that are more important than others? If so, they should be examined from the perspective of all stakeholders. As another example, are there any short- or medium-term goals that serve as the gateway to multiple long-term goals? If so, these gateway outcomes are ones that need to be better supported. While key pathways can be identified using these example questions (among others), they can also be identified using the model itself. These "hubs" are often identifiable visually because they intersect with many other inputs or outputs. Identifying these key pathways at this phase allows instructors to reflect on whether current teaching practices support the most important course goals. It can also help instructors to identify areas of evaluation interest.

Step 3d: Reflection and Further Analysis of the Course Model

After identifying the hubs in the pathway model, a more thorough series of analyses should follow. These will reveal the strengths and weaknesses of the current course design, and suggest new mechanisms to improve the course. In this regard, the model itself provides immediate, formative feedback on aspects of the course that could be strengthened before

resources and effort are allocated to formal evaluation. One of the principles of SEP is the view that the evaluation process and the course itself are dynamic. Each iteration of the model identifies missing components and allows them to be incorporated in a logical way.

Table 2: Suggested Prompts for Model Analysis and Revision

Focus Area	Sample Questions:
Identify Areas for Improvement	**Are there any weak or unsupported connections?** What assumptions did we make when planning a course? Do the activities sufficiently lead to long-term goals? Do the short-term goals adequately prepare the students to achieve medium-, and long-term outcomes? **Does each pathway have the necessary support?** What are the supporting structures for each pathway? Are all outcomes adequately supported? Are there any connections that lack critical support? **Do current assessments accurately measure stated goals?** How is student learning measured?
Use Pathway Model for Course Analysis	**How does the pathway model fit into evaluation planning?** How would you know whether the course is working for all stakeholders? Does the model lead you to new education research questions? What assumptions in your course pathway model would research questions help you answer? Is there literature supporting your research questions? Does this evaluation plan support your research questions?

Step 4: Simplify the Course Pathway Model

Finally, in order to communicate main findings more effectively to a broader group of stakeholders, similarities and themes can be identified within the model. For example, one region of the model may largely support student achievement, whereas another may be focused on building an inclusive classroom. In some cases, related components can be consolidated. At the end of this step, key "zones" are likely to have been identified. These can be considered in

isolation and used to illustrate the main findings or areas of focus within a course. Nevertheless, this is an additional step outside of the Systems Evaluation Protocol (SEP), and the zones are not intended to replace the comprehensive pathway model. It should be used primarily for communication, not comprehensive analysis of a course. For a more comprehensive review of communicating complex pathway models versus simplified zone models, see Reeves et al., (2020).

Table 3: Goals and outcomes of the course

Knowledge Growth	Skills Growth	Motivational Growth	Identity Growth	Other Growth
E.g., Students learn key concepts in anatomy and physiology.	*E.g., Students learn how to judge the reliability of information that they find.*	*E.g., Students feel more comfortable asking for help.*	*E.g., Students identify as members of a learning community.*	
E.g., Students understand relevance and context of biological knowledge.				

Note: Although it is beneficial to consider all aspects of learning gains, it might not be practical for a course pathway model to include all areas. In our model, we chose to focus on gains in skills, motivation, and identity. This worksheet aims to help the users to consider learning outcomes more broadly at first and then determine the focus of the model.

Table 4: Identify the course's key activities

Type of activities	Domain				
	Knowledge Growth	Skills Growth	Motivational Growth	Identity Growth	Other Growth
Course preparation	*E.g., Students watch short teaching videos ahead of class.*	*E.g., Students read primary literature selected by the instructor.*	*E.g., Instructor learns students' names.*	*E.g., Students complete activities that promote growth mindset.*	
In-class	*E.g., Students*	*E.g., Students*	*E.g.,*	*E.g., Students*	

activities	*participate using classroom response system.*	*complete case studies.*	*Instructor discusses news that is related to course curriculum.*	*work in groups to do peer instruction.*	
Other Supporting Activities (homework, TA, etc.)	*E.g., Students complete weekly quizzes.*	*E.g., Students work in groups to prepare for presentation.*	*E.g., Students research cases that are related to the course curriculum.*	*E.g., Students attend office hours.*	

Note: An activity can lead to direct gains in multiple domains and gains in one domain can also have an indirect effect on the others. For example, when students teach each other to solve case studies, they improve communication skills as well as content knowledge. Similarly, growth in motivation and skills can often lead to the construction of a scientific identity. Users only need to include each activity once on this worksheet and list under the category that has the most direct effects.

Table 5: Suggested Mapping and Evaluation Resources

Resource	**Description**	**Resource Location**
Evaluation Netway	The Evaluation Netway is designed for program modelers and evaluators to create models while being connected to an online community of related programs, measures, and practitioners.	www.evaluationnetway.org
Mural	Mural is a newer mapping technology that allows multiple individuals to work on the same model simultaneously.	www.mural.co
The Guide to the Systems Evaluation Protocol (SEP)	The SEP provides readers with a standardized protocol that allows any program, including a course, to conduct an evaluation.	https://core.human.cornell.edu/research/systems/protocol/index.cfm
Research Methods and Knowledge Base by William Trochim,	The Research Methods and Knowledge Base is a useful web-based textbook that may help an evaluator or	https://conjointly.com/kb/

Cornell University	modeler who seeks to build their social research methods knowledge.	

[Supplemental Figure 1] **Full Pathway Model for an Anatomy and Physiology Course.** Pathway Model for Anatomy & 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.