A Directional Map of Learning Objectives for Introductory Physics Courses

Jackson Falk[1] , Amy Furniss[1]
University of California, Santa Cruz[1]

Abstract

Introductory Physics courses are often structured around modules that facilitate lesson planning and segmented content review for students. We summarize the motivation behind and process of developing the learning tool, which utilizes lesson and concept compartmentalization to aid in student success [1]. This tool is an interactive learning map with the course modules and learning objectives for an introductory physics course. By treating each learning objective as an information node and connecting it to others with learning tags that describe its connections, we create scaffolded learning maps where modules visibly build upon each other, or proximity maps that show how closely connected specific concepts are. This map enables students to visualize the relationships between learning objectives, facilitating the creation of review paths. These paths bring the student back to the foundational concepts, which, when lacking, lead to confusion and misconceptions in higher-level concepts. Student-centered applications of this visualization of course content might include creating tracked, personalized self-study and homework assignments that adapt to a student's answers and provide review material based on these connections. Curriculum development applications of maps, such as this, might provide visualizations of how courses are connected and aid in planning majors and sub-majors.

Motivation

Courses built around simple learning objectives that students can follow sequentially often yield better learning outcomes. Our introductory physics courses, taught by several of our professors, use this learning objective format as the foundation for how they teach these classes. We wanted to create a way for students to visualize these courses and their learning objectives. Currently, the students interact with the LOs through a spreadsheet pictured below for Module 3: Newton's Laws.

Module 3: Newton's Laws		Connections
Module-level Learning Objectives	**Label**	
Identify and describe each of Newton's Laws.	A	3B, 3C, 3E, 3G, 4C, 4D, 7D, 8K, 9A, 9H
Identify all the forces exerted on an object.	B	3A, 3C, 3D, 3E, 3F, 3G, 4A, 4B, 4C, 4D, 4E, 4F, 5F, 6B, 6C, 6D, 6E, 6F, 6G, 6H, 6I, 7C, 7D, 8K, 9B, 9C, 9F, 9H, 9I
Represent all the forces exerted on an object with a free-body diagram.	C	3B, 3D, 3E, 4B, 4F, 6B, 6C, 6D, 6E, 6H, 7D, 8K, 8L, 9C, 9F, 9G, 9I
Determine the components of a force from the magnitude and direction of the force.	D	3C, 4A, 4C, 4D, 4E, 4F, 6A, 6B, 6C, 6D, 6E, 6H, 6F, 6G, 6H, 8K, 9B, 9C, 9F
Identify Newton's third law (action/reaction) pairs of forces.	E	3B, 3C, 3D, 4C,4D, 4E, 4F, 7C
Describe situations in which the velocity of an object is a nonzero constant when no net force acts on the object.	F	3A, 3B, 3C, 3G, 4B, 4C, 4D, 4E, 4F, 6C, 6D, 6E, 6F, 6G, 7B, 7D, 9H
Describe what an inertial reference frame is and how it is related to Newton's Laws.	G	3A, 3B, 3C, 4C, 4D, 4E

Review Paths

Using the connections and edges and vertices we can build pathways through the learning objectives based on specific tags. If a student is struggling with a specific idea within a learning objective, we can select that idea and using the edges and vertices draw a path backwards. This use of the edges and vertices will be useful for later portions of the project where we seek to make interactive homework assignments that automatically give you review questions based on what you got wrong in a question.

Review Path in Stacked Rows

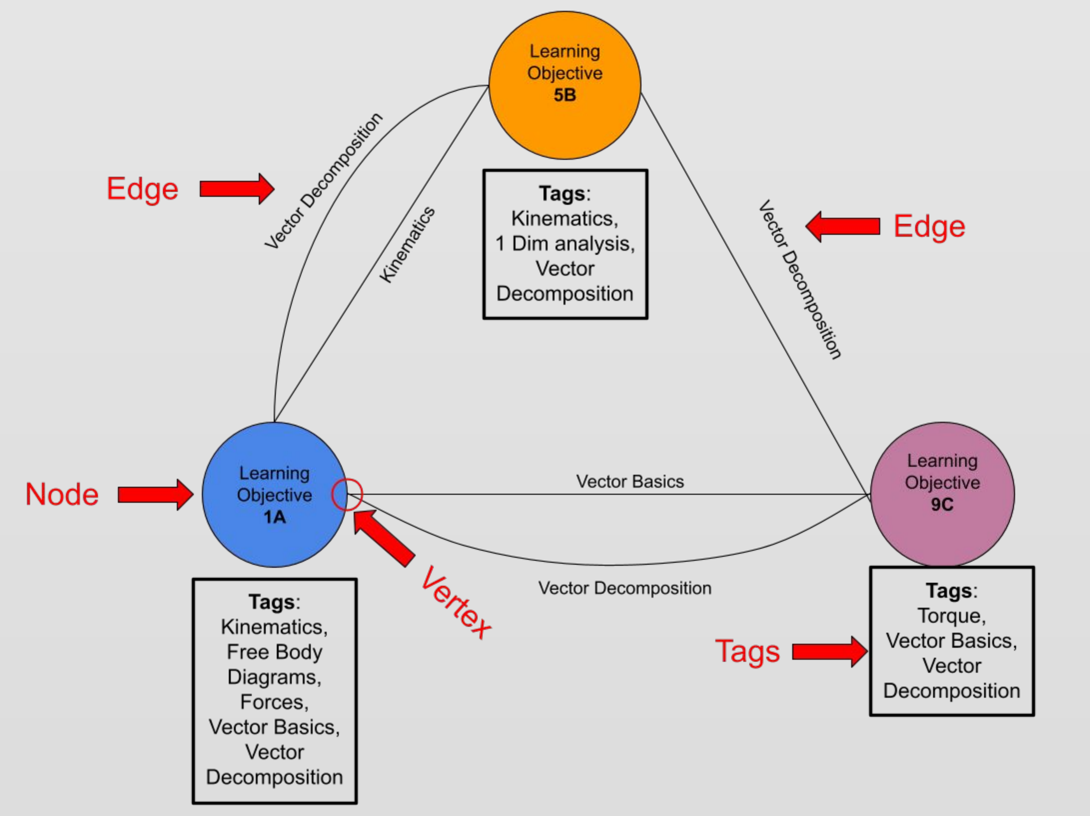
Review Path in Proximity Maps

Data Set

Our Initial dataset consisted of learning objectives written by Professor Amy Furniss for our introductory Mechanics course, Physics 6A. This course is tailored for non-physics majors and is used as the physics requirement for many Biology and pre-med major programs. Each Learning objective is labeled by Module (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) and the specific objective (A, B, C, etc.). Each of these learning objectives was then tagged with a set of 20 physics concepts that describe what concepts the learning objective considers. We then created sets of connections between learning objectives based on our knowledge of the course. We classified three types of connections: forward connections, which are connections from earlier course Learning objectives to later ones; backwards connections, which are the forward connections but reversed; and inter-module connections, which are between LOs in the same Module. For example, 1A, which discusses vector basics, connects to many of the learning objectives later in the course due to its fundamental concepts.

With these classifications, each learning objective effectively becomes a vertex with labeled descriptors and edges connecting it to other vertices. Using this, we can create a concept map that connects each learning objective to the rest of the learning objectives in the course, providing a descriptive and comprehensive overview. Learning objectives that are connected and share a concept tag are considered to have an "edge". If they share multiple concept tags, then they share multiple "edges". Using this concept of edge sharing, we can build pathways through the learning objectives for the course, based on fundamental concepts.

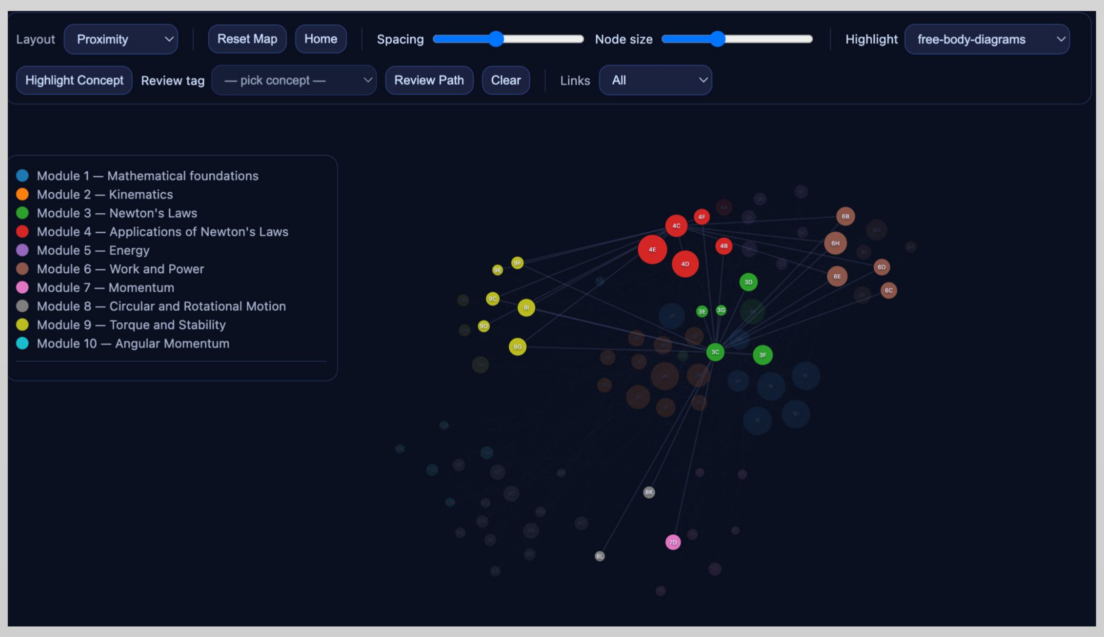
In total, we have 834 connections, each of which is classified with a shared tag between the two connected nodes. These span both forward and backward connections, as a forward connection from 1A to 7B can be considered a backward connection from 7B to 1A.



Caption: Example Diagram to help visualize our data set. A node is considered a Learning objective (LO). Each of these nodes is then classified by a set of tags that describe the learning objective outcome. Each LO is then connected to other LOs based on course teachings, creating vertices on each LO. If two connected LOs share the same tag, a new Edge is drawn between them with that tag as the description.

Concept Highlight

Another function of the concept tags allows us to highlight all of the learning objectives associated with this tag. For example, as demonstrated below, we can highlight each learning objective associated with free-body diagrams.



This function should allow students to visualize what learning objectives they need to review if they are struggling with a specific concept related to the course.

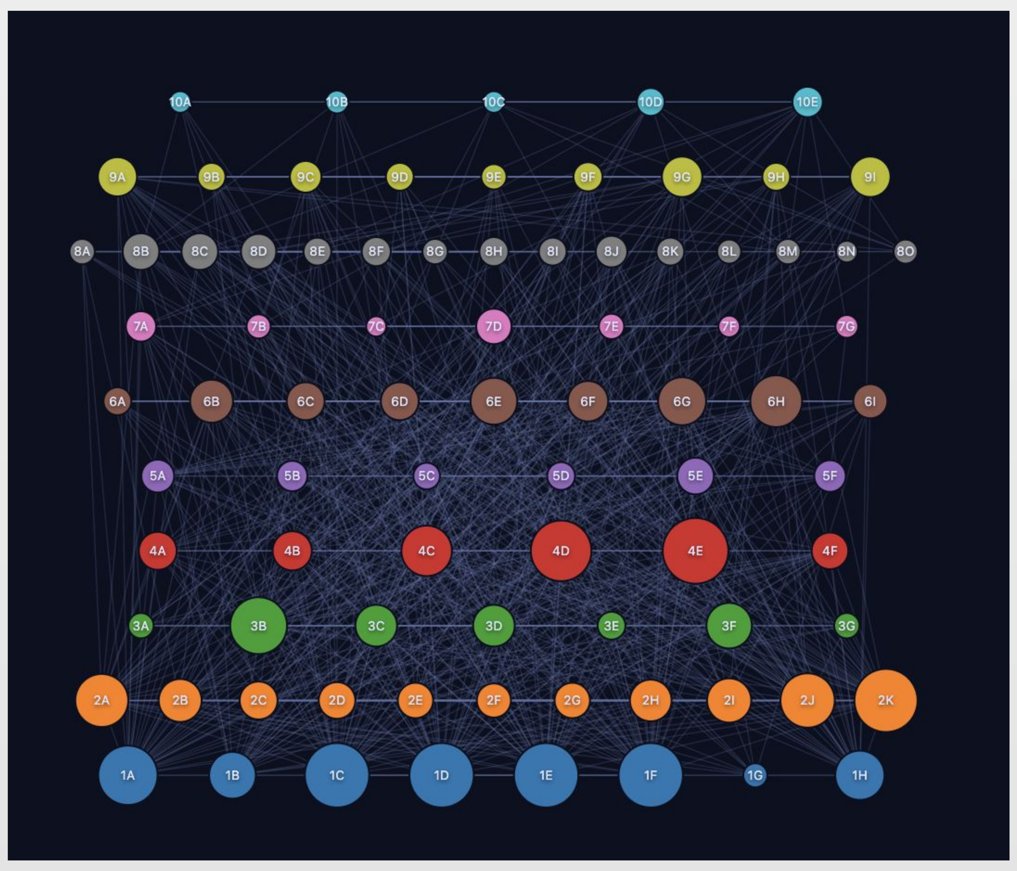
Building the Map

We applied knowledge of the course structure, along with the use of AI to help code the Javascript and HTML portions of the map and develop the actual interface. We provided all of the content and data, while we used an LLM to create the visuals, and functions of the map.

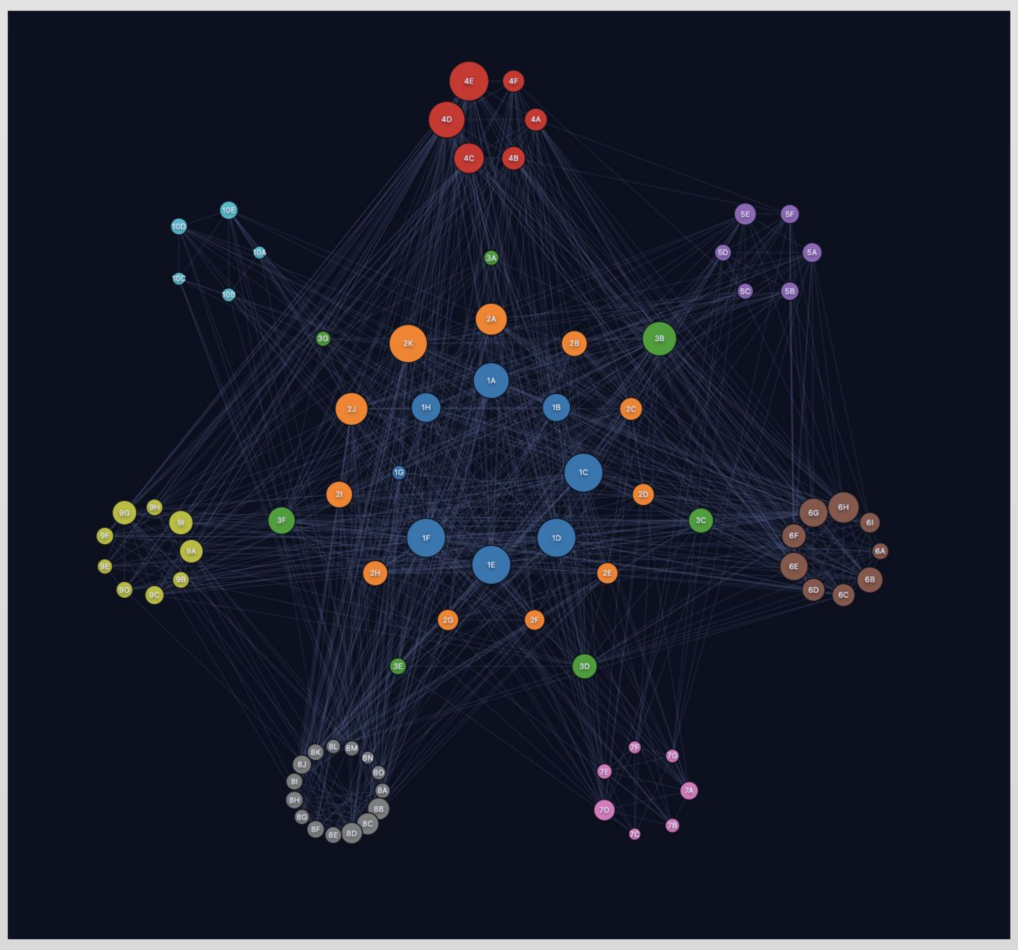
Visualizing the Course

We wanted the students to be able to visualize the entire course through the learning objectives in a way that feels most natural to them. So far, we have developed three map layouts that emphasize the scaffolded approach to learning the LOs try to provide. The first layout is a stacked rows configuration where each Module is stacked on top of the next in numerical order. The second is a concentric rings layout, where the first three modules lie in concentric rings. The remaining modules are arranged as neighborhoods around this inner core. This is intended to highlight the interconnectedness of those initial modules and the importance of mastering their content. The third configuration is a proximity map where each node is scaled and positioned based on the number of connections it has and who it is connected to. Here, it's possible to visualize which LOs from other modules are most connected as they are physically closer. Clicking on any one of the nodes/LOs will display the description and all the other LOs it is connected to.

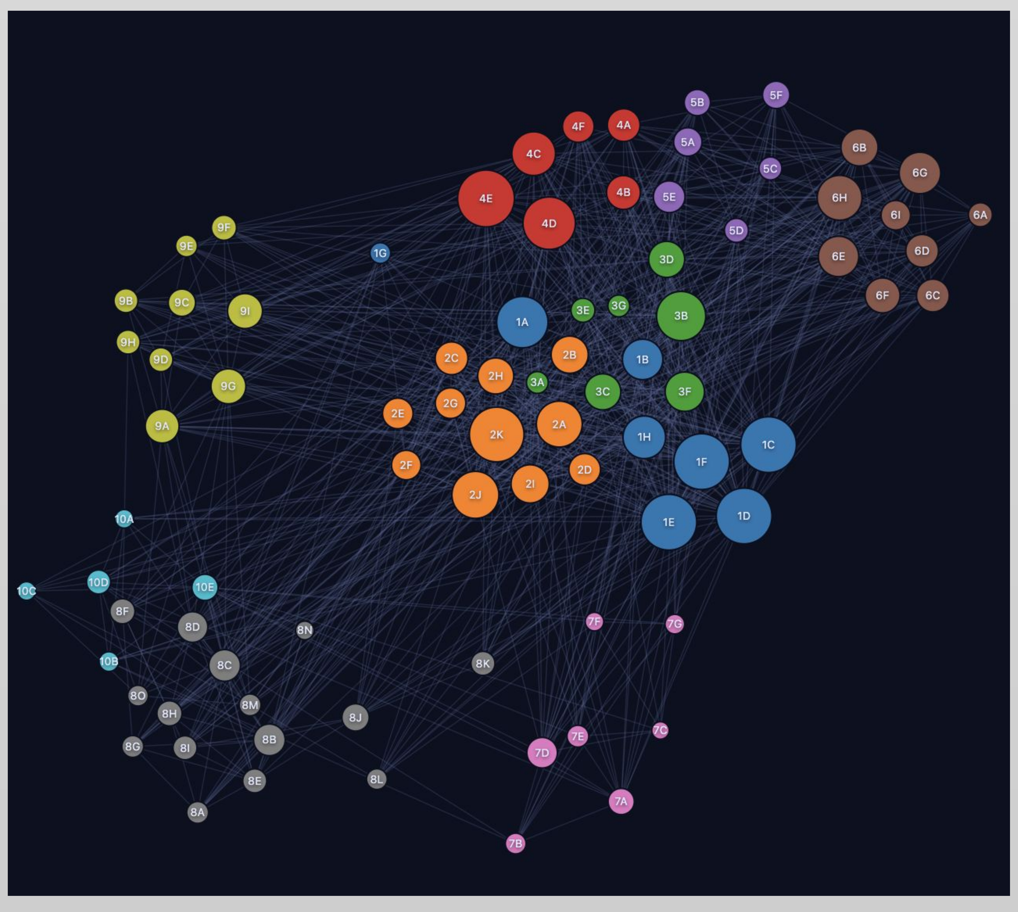
Stacked Rows



Concentric Rings



Proximity Map



Next Steps

Create maps for all intro science courses including Physics, Bio, Chemistry, nd Math. Use this technique to visualize course selection for majors, submajors, and pathways to graduation.

Acknowledgements

1. M.-A. Winkelmes, A. Boye and S. Tapp, *Transparent Design in Higher Education Teaching and Leadership*, Routledge, 2019.