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Mapping Outcomes in an Undergraduate Aerospace Engineering Program

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1 Overview

Student learning outcomes have long been established as an important component in the process of developing subject content, communicating expectations to students, and designing effective assessments.[2] This project focused on mapping the relationships among outcomes across the undergraduate curriculum in the Department of Aeronautics and Astronautics at MIT. Through this project, we expanded upon existing sets of outcomes and created new sets where none previously existed to connect subjects in the undergraduate curriculum in an integrated framework.

While outcomes are often presented as a list,[7] this project connected outcomes by grouping them in modules and linking them in a prerequisite structure. Here, we define a module as a learning unit comprised of a set of outcomes and we define a prerequisite outcome as an outcome which a student is required to have achieved before he or she can learn another related outcome.

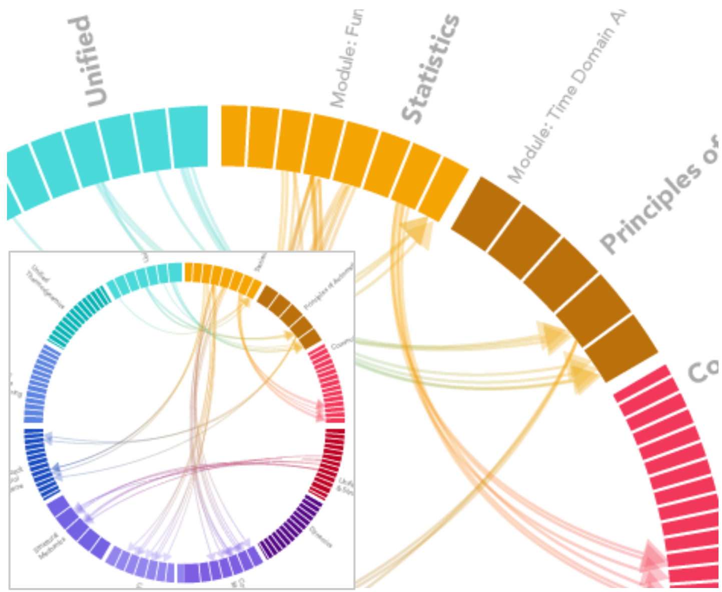

Fig. 1: Visualization of all subjects and modules

Figure 1 shows an overview of the visualization tool developed to display the outcomes and their connections. Each subject shown here is a class that contributes to requirements for the aerospace engineering major. Each of these subjects is divided into a number of modules which each contain a varying number of outcomes. While there are hundreds of intra-module connections (i.e., outcomes within a module connected to other outcomes within that module) and intra-subject connections (i.e., connections between modules within a subject), this figure shows the inter-subject connections. The visualization is interactive and can show different levels of the intra-module, intra-subject and inter-subject connections.

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2 Related Work

Learning objectives emerged in the literature in the late 1950s and 1960s primarily through the work of Benjamin S. Bloom and his colleagues.[2,6,8] Literature in the 1970s and 1980s focused more on pedagogy than on outputs, but a renewed focus on the outputs of education in the 1990s drove a new wave of literature based on learning outcomes and objectives.

In contrast to the methodology used in the widely-cited successor to Bloom's original taxonomy, this project focuses on learning outcomes rather than on learning objectives.[1] While acknowledging the complexity of the debate,[9,10,11] we agree with the assertion in Harden 2002 that learning outcomes and learning objectives are distinct from each other; here, we focus on learning outcomes, since they are better suited for our goals of supporting curricular design.[6]

Learning outcomes defined in this project take many of the properties defined in Harden et al. 1999 while also drawing substantially from the CDIO framework.[3,4,7] In particular, these outcomes match all seven criteria of the framework in Harden et al.: they reflect the mission of the department, they are clear and unambiguous, they are specific, generalizable and manageable, and they are designed in such a way that their interrelationships are clear. However, these outcomes are designed to match a level of specificity beyond what is described in Harden; per the CDIO framework, the space of competencies in engineering and design can be mapped, and it is beneficial to do so at a level of granularity that allows for direct and objective linking of skills.[3,4]

This project makes two primary contributions to the literature on learning outcomes. First, we make direct outcome-to-outcome prerequisite links across an entire undergraduate curriculum and provide evidence to suggest that such links are useful in curricular design. Second, we separate outcomes into relatively self-contained modules and assess their "modularity" as a function of the number inter-module prerequisite links. Outcomes in this project are connected to specific subjects in the curriculum, but these connections stem from the shape of this specific aerospace program and might not exist in the same exact way in other programs.

3 Motivations

A variety of motivating factors drove this project. The primary intent was to increase the ability of faculty to organize material coherently across the full curriculum. With the help of this project, faculty in the department can now more easily see the subjects they teach in a broader departmental context. Faculty can also quickly identify both gaps between subjects and unnecessary overlap. This project has already facilitated conversations between faculty teaching related subjects where these faculty have reconsidered how outcomes are divided across their respective subjects.

In addition to helping faculty integrate their subjects into the curriculum as a whole, the results of this project will serve as an enduring record of both what is taught and what the faculty collectively agree should be taught in the undergraduate curriculum. This will help facilitate a smooth transition when a new faculty member teaches a given subject, as the new faculty member will have a record of what their students are expected to be able to do upon completion of the subject.

This project also anticipates directions in which the department may move in the future. The structure in which the outcomes are grouped helps faculty identify modularity within subjects; in this model, modules vary in the extent to which they depend on other modules via prerequisites. Sets of modules with many prerequisite interconnections are unlikely to be taught independently of each other, but modules with few external links may be separated at some point in the future as the department considers offering more flexibility to students through different types of classes.

These outcomes may also be used as a framework for developing dynamic, integrated assessment. As online learning tools proliferate, faculty gain the ability to design and embed assessments within the resources that they share with students online. One specific example of a first step toward this integration has taken place within a junior/senior-level computational methods subject that utilizes a blended learning model. In this subject, the outcomes map provides an explicit structure that integrates pre-class online readings with in-class active learning activities. Each section of the online readings and the associated embedded assessments are tagged explicitly with the specific outcomes to which they relate. The online platform also provides integrated linkages of all outcomes across the subject, permitting students to navigate through the online resources to find other lessons and assessment activities that relate to each outcome. Figure 2 shows this integration in greater detail- measurable outcomes (MO) 1.9, 1.11, and 1.12 in this subject are referenced directly on the page containing material to which they relate.

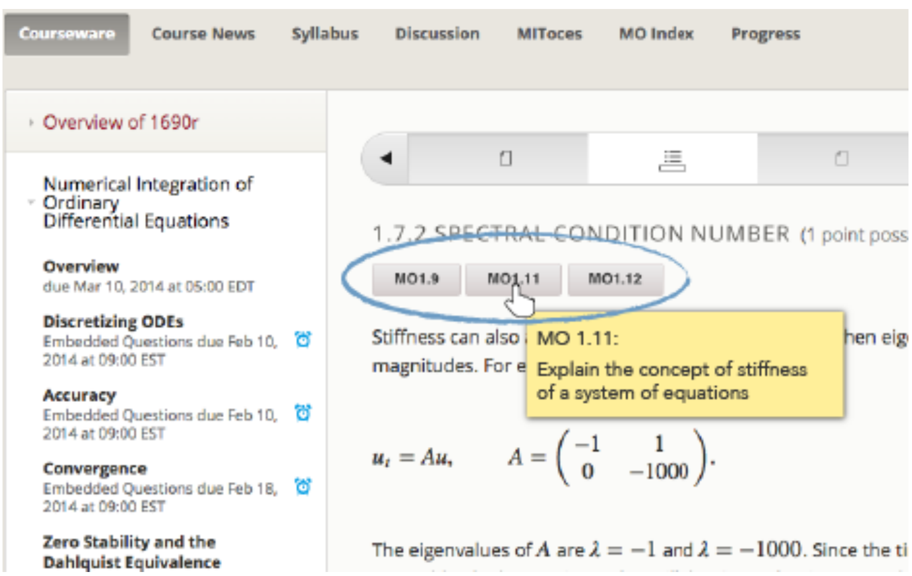

Fig. 2: Outcomes integrated into a computational methods subject

The use of outcome maps in this computational methods subject is also a result of the final motivation for this project – the project team aimed to develop a framework that could serve as a roadmap for students. With the help of visualizations developed for this project, students can see a direct path through all of the outcomes they need to achieve to move from introductory calculus to aerodynamic analysis of flows over an aircraft wing. These maps allow students to know how what they are learning at any given time connects to their broader goals, and can help them assess their own progress.

4 The Model

The fundamental unit of the model used in this project was the learning outcome. Here we define a learning outcome as something a student is able to do after having completed the relevant section of the subject. The collected outcomes were tagged with various properties, including modules, subjects, and prerequisite outcomes. Each outcome was tagged with one or more modules, which are defined as learning units comprised of a set of outcomes, and were designed to be cohesive around a central theme. Though modules were intended to be largely standalone units of learning, in practice the volume of linkages between modules varied across the data set. Each module was associated with the subject in which it is currently taught, but this is not a requirement of the model; in the ideal case subjects would be defined only as groups of related modules, while currently subjects are shaped by external logistical factors such as the length of a semester.

Outcomes in this model are connected by prerequisite relationships. Any outcome may contain pointers to a set of other outcomes which it requires. For an outcome A to require another outcome B, some component of A must require a competency gained in the completion of B. Some outcomes have no prerequisites, and some outcomes have many prerequisites. In this model, prerequisites are considered to be "inherited," so if outcome A requires outcome B and outcome B requires outcome C, it is implicit in the model that A requires C and as such this connection is not restated.

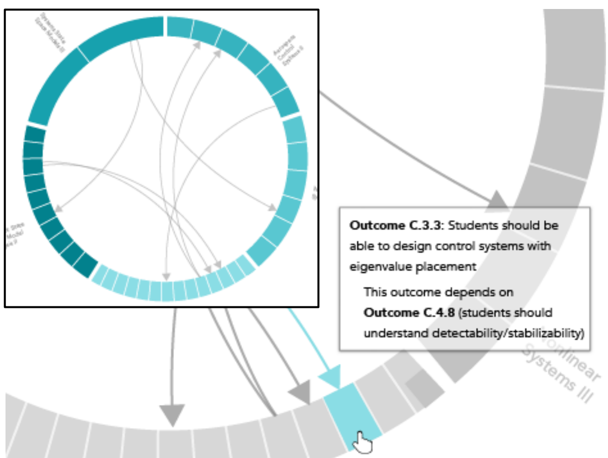

Fig. 3: A feedback controls subject partitioned into five modules

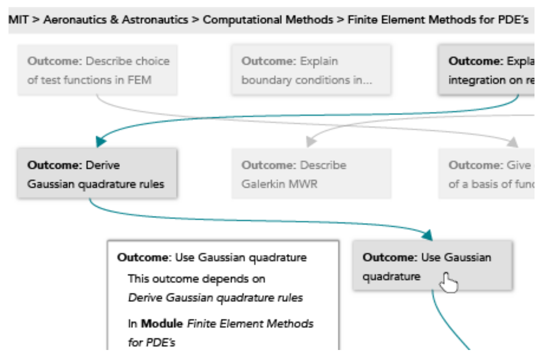

Fig. 4: Outcomes arranged within a module

Figure 3 shows Feedback Control Systems, an advanced subject in the undergraduate curriculum, divided into five modules with between two and fourteen outcomes each. Arrows between modules show connections between outcomes in different modules. Here the larger partitions with text labels are modules, and the smaller partitions are outcomes within each module.

Figure 4 shows one module within the previously-discussed computational methods subject, with arrows connecting outcomes to show prerequisite relationships.

Figure 5 shows two closely-related subjects, a sophomore-level fluids subject and a more advanced aerodynamics subject, and the many connections made between their outcomes. Many outcomes in the fluids subject lead directly to outcomes in the aerodynamics subject.

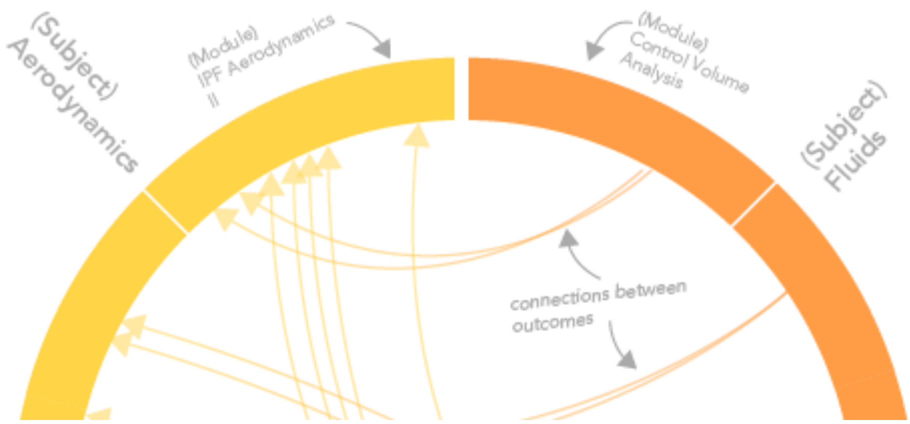

Fig. 5: Interconnections between two subjects

A core strength of this model is that it focuses on what students should be able to do, rather than prescribing a specific mode of delivery. This retains the ultimate goals for each subject while still allowing faculty flexibility in how they approach teaching the material. Furthermore, the focus on outcomes is particularly relevant in a professional major such as engineering, where many students enter industry after graduation. While these outcomes are distinct from outcomes tied to frameworks such as CDIO or ABET, much of the underlying intent is the same.[3,4] A broad perspective on the curriculum can be gained by looking at the integrated set of outcomes that were collected. Students will take different paths (e.g., different technical electives), but in each case the subject-level outcomes will in aggregate fulfill higher-level program objectives.

An interesting area of future work would be to augment this subject-based outcome mapping with a higher-level aggregated mapping to ABET or CDIO outcomes. While the majority of outcomes captured in this framework fall within the Technical category for ABET outcomes, outcomes which address the other four categories are also included. Moreover, outcomes included in this project address all of the Criterion 3 student outcomes a-k, and could in the future be tagged as such.

5 Methods

The comprehensive set of outcomes that emerged from this project required significant time investment and planning to develop. Outcomes were collected one subject at a time using a single repeated process for each subject but allowing for significant variation to match circumstances.

In each case, the project team began with an initial meeting with one of the faculty teaching the subject to outline goals of the project and explore any existing outcomes. If the faculty member had up-to-date outcomes, we worked together to edit the outcomes to fit the project format by adjusting syntax or granularity. If no up-to-date outcomes were available, either the faculty member or the project researcher reviewed subject materials including syllabi, lecture notes, and problem sets to propose a new set of outcomes.

Once an initial set of outcomes was agreed upon, the researcher and faculty member worked together to group outcomes into modules and develop links between outcomes in the subject. After completion and approval of these links and groupings, links were made between outcomes in the subject and prerequisite outcomes in other subjects. This required a complete set of outcomes from prerequisite subjects, so this step often involved some time delay while the preliminary stages in other subjects were completed.

Once preliminary outcomes, modules, and prerequisite links were created for the entire undergraduate curriculum, interest-groups of faculty met to discuss sequences of subjects and revise the outcomes and links within them as they felt was appropriate. These meetings produced a comprehensive draft of outcomes with department-wide approval.

The process used to gather outcomes for the fluids and aerodynamics subjects illustrates these various steps. First, a meeting was scheduled with faculty members who teach both aerodynamics and the corresponding introductory fluids subject. Sets of existing outcomes from both subjects were examined and revised slightly. These outcomes were grouped into modules and links were developed between outcomes both within and across subjects. Finally, the full set of faculty involved in teaching fluids and aerodynamics were offered the chance to comment and additional small revisions were made.

6 Conclusions

Though these outcomes are presented as a final draft, the project was structured to allow for continuous maintenance moving forward. Faculty will be able to edit, remove or add to the current outcome maps with approval from the other faculty in their interest groups, and we are currently developing a user-friendly editing tool for this purpose. We anticipate periodic review of these outcomes to ensure that they remain up-to-date.

This project is nearing completion, and so far, more than 1000 outcomes have been collected from more than 20 subjects in the undergraduate curriculum in Aeronautics and Astronautics and from several of their prerequisite subjects outside the department (e.g., mathematics, physics, materials science). Once finalized, these outcomes will be shared with other interested departments to serve as an example for a structured outcome framework.

While this project may provide significant benefit to the department and the institution as a whole moving forward as described above, the contributions that have already been made have been substantial; numerous discussions have taken place regarding what students in the department should learn, what the progression of learning ought to be, and how this progress can most effectively be tracked.

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