POLICY FORUM

HIGHER EDUCATION

From pipelines to pathways in the study of academic progress

Students and administrators can benefit from new analytics

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Universities are engines for human capital development, producing the next generation of scientists, artists, political leaders, and informed citizens (*1*). Yet the scientific study of higher education has not yet matured to adequately model the complexity of this task. How universities structure their curriculums, and how students make progress through them, differ across fields of study, educational institutions, and nation-states. To this day, a "pipeline" metaphor shapes analyses and discourse of academic progress, especially in science, technology, engineering, and mathematics (STEM) (*2*), even though it is an inaccurate representation. We call for replacing it with a "pathways" metaphor that can describe a wider variety of institutional structures while also accounting for student agency in academic choices. A pathways model, combined with advances in data and analytics, can advance efforts to improve organizational efficiency, student persistence, and time to graduation, and help inform students considering fields of study before committing.

Metaphors are ubiquitous in science to make sense of complex phenomena and communicate findings among scientists and to the public (the "solar system" model of the atom, genes as "blueprints" with molecular "scissors" to "edit" genes, etc.). Yet outdated or biased metaphors can limit scientific innovation and contribute to misunderstandings, even if they are not invoked explicitly, in part because they shape people's embodied cognition. The academic pipeline metaphor has several conceptual problems.

First, it suggests clearly structured and sequenced curriculums. These may be evident in some STEM fields in the United States, and more generally in undergraduate programs in some parts of the world. Yet many colleges and universities encourage breadth and exploration in course-taking, and some even prevent students from declaring majors until the middle of their undergraduate careers (*3*).

Second, the pipeline imagery implies that students are inert substances being propelled through curriculums by external forces. Yet students are active agents in their own academic lives, and their evolving demand for curricular offerings can encourage curricular change over time. Considering curricular structures in isolation of student agency misses how educational outcomes are jointly produced between schools and students.

> **"…the pathways heuristic emphasizes students' participation in their own academic progress…"**

Third, pipelines have clearly specified beginnings and ends, and they minimize "leaks." This metaphor may be apt for some program exits, but many "leaks" are intentional transits between fields of study. Students may continue in an entered program's "pipeline," or "leak" by leaving school. But they may also exercise their ability to move into other domains of study.

Real-world academic contexts are complex, with many schools offering hundreds of academic programs and granting students freedom to move between and combine domains of study in myriad ways. Tracing these movements is important because they represent ongoing investments in human capital by students and sch alike. To move beyond the limitations of the pipeline metaphor, we specify a heuristic of pathways to motivate a next generation of inquiry into academic progress. Research informed by this heuristic can guide interventions at schools with notably different objective functions: increasing timely graduation, broadening participation in specific academic subjects, or encouraging exploration and cross-disciplinary programs of study. Unlike the pipeline imagery, the pathways heuristic emphasizes students' participation in their own academic progress and accommodates positive interpretations of curricular transitions.

We define academic pathways as joint outcomes of available curricular programs (i.e., curricular structure) and considered and selected academic opportunities (i.e., student agency). In contrast with prior uses of the pathways concept [e.g., (*4*)], our definition advances postsecondary theory and empirics because it centers both structure and agency at the same time and recognizes the interplay between them. It enables researchers to see that curricular offerings may elicit variable experiences and responses from different kinds of students. It also offers a mechanism for understanding why curricular offerings might change over time in response to evolution in students' academic choices.

An essential aspect of the pathways heuristic is that it accommodates all possible routes between academic origins and destinations, akin to how streets comprise the entirety of possible routes through particular cities. Just as cities differ in their topography and design, curricular programs at different universities—or even across divisions within any given school—render the task of navigation highly variable. Observation and comparison of different curricular and organizational designs are necessary for a full understanding of academic pathways and their implications for student progress. Students navigating specific curriculums will confront sequences of academic choices with—or without—maps or prior experience. Some may be able to leave academic decisions entirely to prescribed directions or expert guides, whereas others may rely only on gut instinct and what others around them are doing at particular junctures.

Curriculums place limits on how academic progress can unfold at any given point in time, but they also can evolve as student preferences and choices shift. Just

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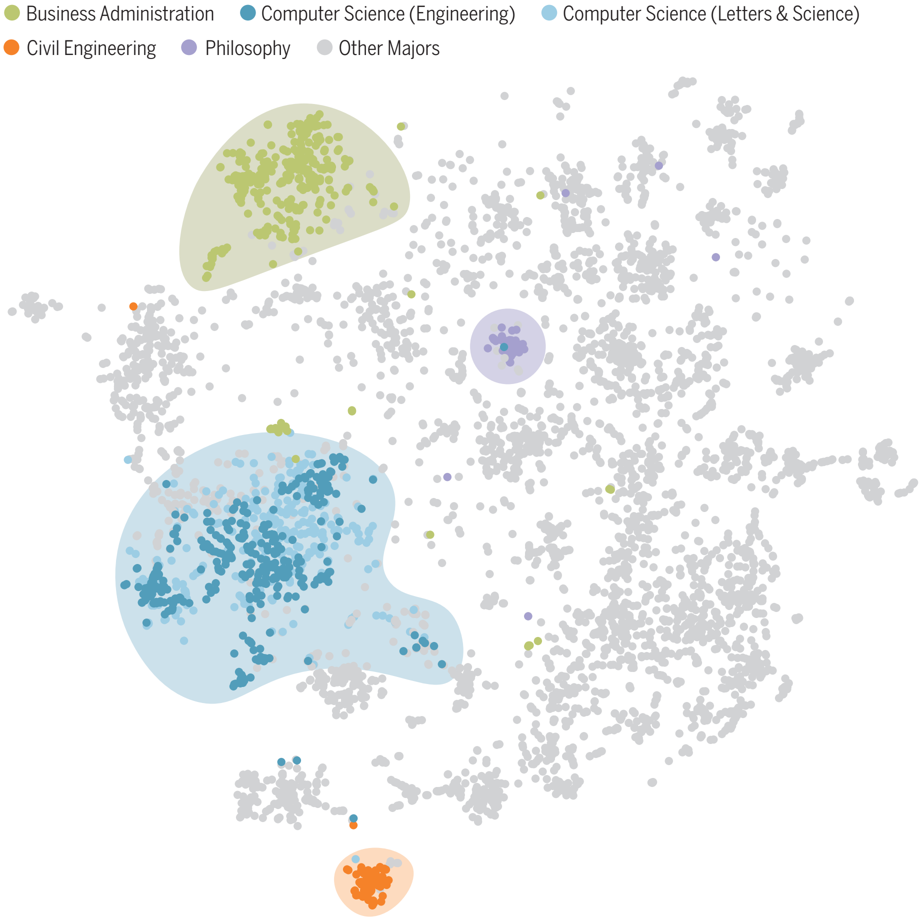
Mapping course enrollment pathways

Pathways are visualized for 6103 UC-Berkeley undergraduates across all majors from matriculation to their last year. Each point reflects a student, and a smaller distance between points reflects more similar course sequences taken. Some majors (e.g., computer science, business administration) accommodate wider variation in paths, whereas others reflect more narrow paths (e.g., civil engineering, philosophy).



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as the builders of physical cities create new structures and entire neighborhoods to meet changes in consumer demand, university administrators may refashion established curriculums and create new ones as student behaviors and the character of knowledge and work evolve.

Two key factors for academic progress are better captured in this imagery than by the pipeline metaphor. First, students are active agents in their education. Their experiences and feelings may influence academic decision-making. Choices may be imbued with meanings and shaped by social norms about what academic options are appropriate for certain kinds of people. Just as people navigating cities may avoid certain streets or neighborhoods because of inherited reputations and biases, students may avoid academic domains on the basis of cultural associations. Domains requiring advanced coursework in mathematics, for example, are variably appealing to students depending on their prior experiences and dispositions toward math (*5*). Different domains also have gendered connotations, variably associated with women and men (*6*).

Second, academic pathways are contingent. Early choices may foreclose subsequent ones, such that paths not taken early in an educational career may be unavailable for selection later. Parents, peers, and professional advisers can influence course consideration and choice. So too can coincidences of calendars and course schedules. Nascent course recommender systems are emerging as additional sources of guidance for forging academic pathways (*7*). This plurality of influences means that academic progress is considerably more complex than the imagery of pipelines implies.

APPLIED SCIENCE OF PATHWAYS

The pathways heuristic encourages new practical applications and scientific investigations. The wide array of production functions of universities creates substantial variation in academic programs, formats, and procedural rules; these define how students can navigate an academic setting at a point in time (*1*). For instance, major requirements vary substantially in their complexity, which can aid or hinder academic progress (*8*). Prior work grounded in the pipeline heuristic has primarily relied on statistical techniques such as cross-tabulation, conditional probabilities, and Sankey visualizations to describe enrollment patterns by focusing on relatively few academic sequences through specific fields of study. These techniques can reveal popular paths into majors, and courses within majors, to students and administrators. They can be used to map and analyze curricular structures. New analytics toolkits, such as the Program Pathways Mapper of the California Community Colleges, and Curricular Analytics by the Association for Undergraduate Education at Research Universities, represent substantial advances in enabling schools and students to analyze the structure of their academic programs.

However, extant approaches are limited in three ways. First, many toolkits focus on curricular structure without considering how students actually navigate these structures to identify consequential patterns. Second, prevailing techniques for analyzing administrative data cannot accommodate wide empirical variation in how students navigate offerings, which may allow tens of thousands of routes through the same set of courses. Third, research programs relying entirely on administrative data, which document only chosen courses, cannot capture the process by which students consider courses, especially ones they do not take. A comprehensive science of academic progress should include both more sophisticated computational strategies and modes of inquiry that fully capture student agency and decision-making.

Computational modeling

Computational techniques from artificial intelligence and machine learning can enable more nuanced insight into how academic progress unfolds under conditions of curricular complexity. Consider a study that used recurrent neural networks to summarize the course enrollments of graduating seniors across all majors at the University of California, Berkeley (*7*). The resulting visualization of student pathways (see the figure) revealed majors that accommodate wide variation in student paths, such as business administration and computer science, and majors that yield fewer paths, such as civil engineering and philosophy. The analysis also reveals the proximity of majors and courses within them in terms of students' enrollments. Advisers and students might use such information to see adjacencies among programs, for example, to find alternative majors with similar course-taking paths. Administrators and students might use similar representations to identify course equivalencies between 2- and 4-year institutions to aid in "articulating" credits for student transfer (*9*). These applications have implications for equity in academic progress, because students approach the task of navigating university curriculums with variable amounts and kinds of knowledge in ways that correlate with socioeconomic advantage (*5*). Leveraging administrative data to improve curricular design, information, and articulation would help to democratize this knowledge.

Network analyses and interactive graph visualization techniques applied to enrollment data can reveal both the structure of prominent curricular pathways into different majors, and also important forks in paths (*10*). Students and advisers could benefit from being able to pinpoint the last opportunity to pursue a particular major given a student's prior coursework, and foreseeing critical forks, such as a failed course, that predetermine departure from a particular program. Causal discovery methods can be used to predict how specific curricular changes would influence students' movement into and away from various programs of study to help administrators design requirements and information interventions to advance equity goals. Insights about academic pathways can also be shared directly with students and advising staff using interactive institution-specific data visualization systems to increase their awareness of potential pathways and anticipate critical choice points (*11*).

Finally, modeling academic progress using a pathways approach might substantially inform ongoing curriculum design. It would enable researchers and administrators alike to see existing curricular overlaps and distinctions to inform changes in offerings and requirements to suit particular educational objectives: balancing curricular breadth with efficient progress toward graduation; and responding to changes over time in students' demand for coursework in particular domains.

Student consideration

Students' academic priors, organizational knowledge, identities, and college experiences shape how they make sense of academic options (*12*). Before students commit to a field of study or even enroll in a single course, they must first consider their options. This involves a multistage winnowing process among a myriad of possibilities to derive a cognitively manageable number of options (*13*). This essential and consequential part of students' agency is rarely observed empirically. Qualitative research has shown that early college experiences can be fateful for academic progress; for example, a bad experience in a single early course can dissuade students from considering a second course in an entire domain of inquiry (*12*). Identities associated with demographic characteristics are also fateful for academic consideration (*6*). For example, a recent survey of community college students found large gender gaps in students' consideration of different academic majors, with women considering fewer STEM majors (*14*).

Academic consideration can be digitally mediated in ways that support students' decision-making and also render the process observable at scale. For instance, online program catalogs or course information systems can be instrumented to log search queries and clicks to observe course consideration behaviors; these can then be linked to subsequent course enrollments and program choices to identify early indicators of these choices (*15*). Yet behavioral data and computational methods alone will be insufficient to fully understand the academic consideration process. Qualitative research has shown that students experience course consideration as a complex task and use various strategies to make enrollment decisions (*3*, *5*, *12*, *15*).

> **"If thoughtfully designed, a distributed science of academic pathways might offer substantial value to lower-resourced institutions…"**

Investigations of consideration will highlight new opportunities for when, and for whom, information interventions might expand awareness of course options to redress underrepresentation in specific academic domains. Controlled experiments in which researchers strategically vary the amounts and kinds of information and options available to students at fateful junctures can help identify mechanisms for revising preferences, eliciting academic exploration, and encouraging informed commitment. Conveying likely consequences of different academic choices to students ahead of time may be one of the most valuable applications of pathways science.

DISTRIBUTING PATHWAYS SCIENCE

Applications of pathways science will be useful to a wide range of institutions and can be made broadly accessible by building a shared analytical framework and data infrastructure. The data and computational methods to model pathways with administrative records are already in place; still under construction are shared units of measurement and techniques for the analysis and visualization of academic pathways. Once these are in the scientific public domain—for instance, as open-source online tools—they will be affordable enough to become routine. Proprietary software tools that are widely used by institutions to store and manage academic records can scale new measures and techniques by integrating them into their platforms. We believe that the analytic framework seeded here is sufficiently flexible to accommodate analyses of academic progress in a variety of contexts, worldwide, wherever administrative data capturing academic sequences are routinely collected and retained.

A pathways research infrastructure would specify a standard data schema to scale the application of the analytic framework. Colleges and universities already keep digital academic records in similar formats. The feasibility of this kind of data standardization is evident in projects such as the National Science Foundation–funded Multiple Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), which curates academic transcript and demographic data across several institutions to enable research on engineering education. Large systems of schools with a common data infrastructure can especially benefit from pathways science, because a single data transformation enables each school to gain curricular insights for its administrators, faculty, staff, and students. We see evidence of this potential for scaling analysis across schools in tools such as the Program Pathways Mapper across California Community Colleges or Curricular Analytics, which is school-agnostic. If thoughtfully designed, a distributed science of academic pathways might offer substantial value to lower-resourced institutions and multicampus consortia; common data standards and analytic applications would enable interoperability and the sharing of costly data-science capacity.

Developing a comprehensive science of student agency also requires a distributed research effort, because understanding consideration and decision-making strategies in context entails relatively fine-grained (and thereby expensive, and harder to standardize) methods of data collection. Yet here, too, thoughtfully designed collaborations and comparative studies among differently resourced schools serving students from different backgrounds will yield portable scientific insights.

A comprehensive and open science of academic pathways will both enable and oblige educators to confront hard choices of organizational design. For example, to what extent should universities encourage academic breadth and exploration rather than “efficient” completion of college degrees? Should academic planners merely follow the evolving preferences of students as they enact their agency in choosing courses, or is shaping and constraining student preferences also part of their job? If students at institutions with high levels of curricular choice commit to programs in ways that sort and segregate by demographic or socioeconomic background, do educators have obligations to make informational or curricular interventions? How should ultimate responsibility for academic progress be apportioned between university administrators, classroom teachers, institutional researchers, and students themselves? Transparent empirical inquiry and thoughtful predictive modeling of academic paths can inform the deliberation of such questions. ■

REFERENCES AND NOTES

1. J. Owen-Smith, *Research Universities and the Public Good: Discovery for an Uncertain Future* (Stanford Univ. Press, 2018).
2. Y. Xie, A. Killewald, *Is American Science in Decline?* (Harvard Univ. Press, 2012).
3. E. Cech, *The Trouble with Passion: How Searching for Fulfillment at Work Fosters Inequality* (Univ. of California Press, 2021).
4. D. Jenkins, S. W. Cho, *New Dir. Community Colleges* **2013**, 27 (2013).
5. M. H. Harrison, P. A. Hernandez, M. L. Stevens, *Sociol. Educ.* **95**, 133 (2022).
6. S. Thébaud, M. Charles, *Soc. Sci. (Basel)* **7**, 111 (2018).
7. Z. A. Pardos, Z. Fan, W. Jiang, *User Model. User-adapt. Interact.* **29**, 487 (2019).
8. D. M. Grote, D. B. Knight, W. C. Lee, B. A. Watford, *Community Coll. J. Res. Pract.* **45**, 779 (2021).
9. Z. A. Pardos, H. Chau, H. Zhao, “Data-assistive course-to-course articulation using machine translation” in *Proceedings of the Sixth ACM Conference on Learning@Scale* (2019), pp. 1–10.
10. G. Angus *et al.*, “Via: Illuminating academic pathways at scale” in *Proceedings of the Sixth ACM Conference on Learning@Scale* (2019), pp. 1–10.
11. Y. Chen *et al.*, “Pathways: Exploring Academic Interests with Historical Course Enrollment Records” in *Proceedings of the Ninth ACM Conference on Learning@Scale* (2022), pp. 222–233.
12. D. F. Chambliss, C. G. Takacs, *How College Works* (Harvard Univ. Press, 2018).
13. E. Bruch, F. Feinberg, *Annu. Rev. Sociol.* **43**, 207 (2017).
14. R. Baker, G. A. Orona, *AERA Open* **6**, 2332858420937023 (2020).
15. S. Chaturapruek *et al.*, *AERA Open* **7**, 2332858421991148 (2021).

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A researcher handles a *Psilocybe* mushroom at the laboratory of Numinus Bioscience in Nanaimo, British Columbia, Canada. The company specializes in psychedelic-assisted therapies.

BIOMEDICINE

Pressing regulatory challenges for psychedelic medicine

Policy must support generation of evidence on safety and effectiveness

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Over the past decade, research on potential therapeutic benefits of psychedelics has demonstrated promise and generated enthusiasm. The number of psychedelic clinical trials has grown dramatically, and there has been considerable private investment and regulatory interest in psychedelic drug development around the world. But this is a complicated moment for regulators seeking to impose a traditional regime of clinical trials and pharmaceutical premarket approval to a class of drugs already used outside the medical establishment through a patchwork of state and local regulation, Indigenous use, and “underground” consumption. It is difficult to anticipate how these approaches will intersect given the challenges of studying illicit use. Meanwhile, pressure from investors and public expectations may exceed the current reality of limited evidence regarding the clinical benefit of psychedelics. Against this backdrop, we focus on pressing regulatory issues that demand attention, creativity, and collaboration to maximize psychedelics’ therapeutic potential.

REGULATING THE THERAPEUTIC CONTEXT

Studies suggest that psychedelics facilitate neuroplasticity of the brain by activating serotonin 2A receptors, allowing the brain to form and reorganize neural networks. Several psychedelics are being studied in combination with psychotherapy, on the hypothesis that the psychedelic experience will augment the therapeutic process and accelerate healing that might otherwise take

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