Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-025-06126-7 OPEN

Check for updates

Has higher education become more interdisciplinary? a longitudinal analysis of syllabi using natural language processing

Youjin Hong[1], Byungjun Kim[2], June Jeon[1]✉ & Lanu Kim[1]✉

Despite the increasing emphasis on interdisciplinary research in universities, we know little about the extent to which university education is interdisciplinary. This study investigates whether higher education has embraced interdisciplinarity. By applying natural language processing techniques to a dataset of 478,233 syllabi from 2004 to 2019, our analysis examines three key dimensions: lexical, topical, and pedagogical. Contrary to the prevailing narrative of growing interdisciplinarity, the findings reveal remarkable stability in the disciplinary boundaries of course content. Lexical analysis indicates minimal convergence in terminology across disciplines, while topical analysis shows consistent topic distributions within broad academic fields. Similarly, pedagogical strategies, as evidenced by the verbs used in learning objectives, display no significant shift toward interdisciplinary actions as outlined in Bloom's taxonomy. These results suggest that despite institutional rhetoric, interdisciplinary education remains largely static, emphasizing the need for deliberate institutional strategies to better align educational practices with interdisciplinary research goals.

[1] Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea. [2] The Academy of Korean Studies, Seongnam-si, Republic of Korea. ✉email: junejeon@kaist.ac.kr; lanukim@kaist.ac.kr

Introduction

Has higher education become more interdisciplinary? How have different academic disciplines been impacted by each other in their classrooms, and what does any resulting change look like? Scholars have extensively argued that interdisciplinary research and education are critical factors behind innovations and discoveries (Bromham et al., 2016; Van Noorden, 2015). Sociohistorical contexts surrounding higher education institutions also demand the dismantling of disciplinary boundaries (Jacobs and Frickel, 2009; Townsend et al., 2015; Vereijken et al., 2023; Weingart and Padberg, 2014). Universities transform toward different "modes" of interdisciplinarity, especially when problem-solving, and patent and product development become their survival strategies (Gibbons, 1994, 2000; Nowotny et al., 2016). Therefore, interdisciplinarity in universities far exceeds individual-level collaboration—it includes organizational and institutional responses to rapidly changing social, economic, and thus educational needs (Kleinman et al., 2017). Under such organizational circumstances, universities adopt similar norms and slowly mimic each other, not only in their formal structure, but also in their understanding of what counts as best practice in higher education institutions (Berman, 2012; DiMaggio and Powell, 1983; Meyer and Rowan, 1977; Sá, 2008). In summary, a systematic transformation toward the interdisciplinary university is becoming a widespread phenomenon, in both empirical and normative senses.

However, despite evidence of increasing trends in interdisciplinary research and development in universities, it still remains unclear how university education has responded to these changes. While the number of interdisciplinary degree programs has reportedly grown, and interdisciplinarity has been adopted as a core rhetorical keyword that symbolizes program innovation (Bear and Skorton, 2019; Wilson, 2010), there is a notable lack of comprehensive evidence regarding the extent to which classroom content and pedagogies have truly transformed. Classrooms are often treated as "black boxes" in higher education institutions, and despite countless organizational changes, the content taught and tested in classrooms remains largely inaccessible for external scrutiny. In this regard, we raise a set of critical questions: To what extent have university classrooms become truly interdisciplinary? If they have, in what specific ways? And, how have different disciplines adopted interdisciplinarity in distinct ways?

To answer these questions, it is imperative to analyze university classrooms in practice—which courses are taught, how educational goals are set and presented, what contents are covered throughout the semester, and most of all, how interdisciplinary components are introduced into the design and practice of university lectures. Qualitative case studies have shown that university lectures oriented toward problem-solving, real-world solutions, and university-wide multidisciplinary collaborations successfully attract students from multiple disciplines (Klaassen, 2018; Lindvig et al., 2019). Still, there are apparent challenges in interdisciplinary classrooms (McGregor, 2017), such as difficulties in communication among students, a superficial level of collaboration, and a mismatch between faculty and students' expectations (Frodeman and Mitcham, 2007; Holt et al., 2017; Vereijken et al., 2023). In other words, university classrooms are going through the paradox of interdisciplinarity, as Weingart once pointed out (Weingart, 2000). Despite apparent demands for crossing disciplinary boundaries in research and education, the reality of the pedagogical application of interdisciplinary education might suffer from the widening gap between evermore specializing subdisciplines. That said, it becomes more pressing to understand the comprehensive *status quo* of interdisciplinary classrooms beyond qualitative case studies.

This paper analyzes 478,233 university classroom syllabi, spanning from 2004 to 2019, obtained via the Open Syllabus database, to identify macro patterns of interdisciplinary education in universities. A syllabus explicitly outlines the course title, content, objectives, and schedule, making it a rich source of qualitative data that reflects a course's underlying educational intentions, including its interdisciplinary orientations. Natural Language Processing techniques are particularly well-suited for analyzing macro patterns in such qualitative data. Moreover, the Open Syllabus database offers an opportunity to examine longitudinal patterns across thousands of syllabi from various disciplines. By leveraging syllabi text data, our study is among the few to utilize this extensive archive for computational analysis, helping to enable understanding of the changing (or surprisingly, unchanging) dynamics of interdisciplinarity in higher education institutions.

To be specific, we offer three layers of longitudinal analyses on syllabi text: lexical, topical, and pedagogical. A lexical analysis analyzes apparent changes in vocabulary in course titles and descriptions throughout the years. It effectively testifies how much universities "seem to" offer more interdisciplinary courses. The result shows a surprising stability in disciplinary language, which means that semantic distance between disciplines has not decreased over time. Secondly, a topical analysis of course syllabi examines the composition of various topics within each discipline. We found that all disciplines show relatively stable distributions of course topics. Finally, pedagogical strategies across disciplines were identified by analyzing frequently appearing verbs in syllabi. These verbs (such as *argue, hypothesize, or propose*) underline both the practical modes of interaction in courses and the pedagogical strategies employed by instructors. Here, we posited that the educational programs in universities have changed to pursue more complex educational goals because interdisciplinary research requires integrating disciplinary knowledge in creative ways to solve unprecedented societal issues, such as climate change (Weingart, 2014; Wagner et al., 2011). In line with previous analyses, there were no significant changes in the major action verbs used in course syllabi, indicating a static pattern in pedagogical approaches. In summary, whether analyzed lexically, topically, or pedagogically, there is no macroscopic evidence that higher education has become increasingly interdisciplinary.

Literature review

Interdisciplinarity in higher education. Scholars have discussed the definition and importance of interdisciplinarity in the context of its application in higher education. According to Julie Thompson Klein and William Newell, interdisciplinary studies are defined as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession (Klein and Newell, 1997, p. 3)." This definition outlines the core components of interdisciplinarity. First, it is a problem-oriented approach to research and education. This aligns with the changing role of universities, shifting from traditional knowledge creators (Mode 1) to problem-solving institutions (Mode 2) (Gibbons, 2000). Numerous qualitative studies have demonstrated how universities engage socially to solve complex problems by employing an interdisciplinary approach (Ashwood et al., 2014; Bell, 2004). Second, interdisciplinary studies mobilize multiple disciplinary knowledge and approaches to accomplish difficult tasks. This distinguishes interdisciplinarity from multidisciplinarity (i.e., the mechanical connection of separate disciplines with a clear division of intellectual labor) and transdisciplinarity (i.e., the emergence of a completely new framework of knowledge beyond disciplinary divisions) (Klein, 2010). Third, interdisciplinarity is a process, not a static result. This means that interdisciplinarity in higher education is realized not only through the results of research projects but also through undergraduate and graduate education in classrooms, research laboratories, and fieldwork.

With a relatively stable definition of interdisciplinarity, educational studies have focused on quantitative evaluations and qualitative case studies of interdisciplinary education. Nevertheless, despite numerous studies, a computational social science approach to comprehensively analyzing higher education institutions' interdisciplinary education remains relatively unexplored. Notable exceptions include computational studies based on the Open Syllabus archive that examine the skills taught in US higher education curricula (Javadian Sabet et al., 2024). The study concluded that the skills presented in university syllabi increasingly embrace problem-solving capabilities and industry demands. However, the study did not focus on interdisciplinarity as a major characteristic of problem-solving-oriented pedagogy. In STEM (science, technology, engineering, and medicine) fields, engineering-led interdisciplinary educational curricula have reportedly been adopted by global universities (Gim et al., 2025). However, this study only examined the status quo of STEM fields, excluding the arts, humanities, and social sciences. Furthermore, it only analyzed course titles and department names to calculate the Curriculum Synergy Score—a new measurement that represents interdisciplinarity among departments. It means that our paper is one of the first attempts for comprehensive computational analyses on the entire academic disciplines, targeting detailed language written in syllabi.

Organizational contexts of interdisciplinary education. The integration of interdisciplinary value into universities' research and education is certainly mediated by institutional and organizational dynamics. Even when urgent social problems, such as global climate change, motivate researchers to collaborate across disciplines, the department-based organizational structure of universities can hinder cross-departmental efforts. Conversely, the institution's incentive structure can trigger recombinant efforts among different disciplines, especially when external political and economic factors promote interdisciplinary efforts (Frodeman et al., 2016). Scholars argue that the formal organizational structure and informal organizational culture of a university are vital to nurturing interdisciplinarity in higher education (Sá, 2008; Weingart, 2014). One of the challenges that most universities often face is structural conservatism because the traditional departmental structure governs resource allocation and faculty recruitment processes within a university. Weingart also mentioned that faculties tend to avoid interdisciplinary teaching, and students, indeed, lose motivation to take interdisciplinary education, because university-wide culture signals that career opportunities of interdisciplinary pathway would be limited (Weingart, 2013). In other words, the extent to which universities engage in interdisciplinary efforts represents the institutional forces regarding how much they promote interdisciplinarity.

Particularly, as Weingart pointed out, interdisciplinary education is one of the hardest organizational outcomes for universities, because of the systematic mismatch between traditional, discipline-based formal organizational structures and the interdisciplinary content that would be delivered in courses. This challenge poses the puzzling question on the interdisciplinary education in higher education—given the strong organizational inertia toward interdisciplinary research, how much have these organizational forces impacted interdisciplinary education in universities? If an institution's normative and cultural forces toward the interdisciplinarity are stronger (DiMaggio & Powell, 1991) than the resistance of the discipline-based educational system in universities, then interdisciplinary education would be as active as interdisciplinary research. However, if the educational boundaries of departments are more strongly protected (Weingart, 2013) than institutional forces, the result would be reversed.

Whether the promotion of interdisciplinary education has been successful amidst discipline-centered universities remains an empirical question. From here, we present our data and analytical strategies for empirically examining the temporal changes of interdisciplinary education.

Data and methods

Data. We accessed course curricula by collecting course syllabi uploaded to Open Syllabus (https://www.opensyllabus.org). We chose to analyze syllabi instead of other data sources such as course catalogs because syllabi provide rich information about higher education curricula through sections such as course descriptions or learning objectives. Open Syllabus is a non-profit research organization collecting millions of syllabi. The main purpose of its data collection is to encourage colleges to share more syllabi, which can help textbook authors, professors, and curriculum developers (Nowogrodzki, 2016). While Open Syllabus has collected syllabi from around 140 countries, about two thirds of the syllabi are from the United States, the United Kingdom, Australia, and Canada. Open Syllabus data are collected primarily by crawling publicly accessible university websites and are regularly updated (Open Syllabus, 2023). The syllabi data in Open Syllabus have been repurposed multiple times in previous literature, which substantiates its reliable quality and scale of the data (Biasi and Ma, 2022; Bourrier and Thelwall, 2020).

From the Open Syllabus database, we collected syllabi from 2004 to 2019, a period that precedes the outbreak of Covid-19. Since Covid-19 brought substantial challenges to higher education, many of which have not been fully resolved, we restricted our analysis to the pre-pandemic era. We further limited our dataset to syllabi from four-year colleges and graduate schools in the United States in order to ensure a relatively coherent empirical scope. Our collected syllabi covered 62 academic disciplines as defined by Open Syllabus. We web-scraped up to 10,000 syllabi per year for each discipline in June, 2023 because the website limited users to access 10,000 syllabi per search. Year and discipline were the most effective filters for narrowing down search results, but this still left us unable to collect complete data when search results returned more than 10,000 syllabi. We contacted the organization for help with this issue, but they were not able to provide a solution that met our needs. While the scraped syllabi included various class-related details such as reading materials, our analysis focused on the course titles and course descriptions to explore the intellectual nature of the courses. We also considered analyzing the reading materials as previous literature on interdisciplinary research often measures interdisciplinarity by examining the composition of a reference list. However, we dropped these data because there are too many missing values, which may undermine the study's robustness. When we checked the five largest disciplines (business, mathematics, computer science, English literature, engineering), approximately 48% of syllabi lack any information about reading lists. We also used learning outcomes to detect pedagogical strategies. However, this section should be interpreted with caution because 39% of syllabi lack information in this section. The missing data were more or less evenly distributed across all five broad fields. Additionally, we used the disciplinary categories assigned by Open Syllabus and recorded the year each course was provided.

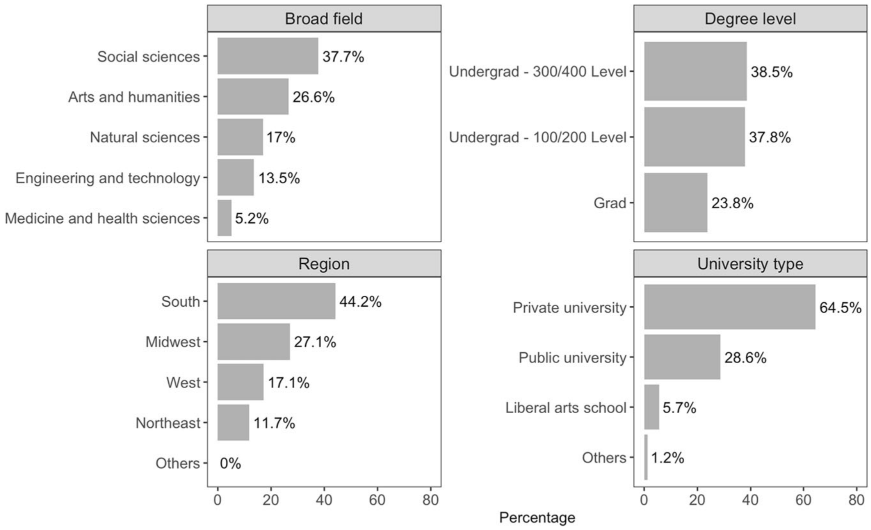

Fig. 1 Descriptive statistics of the analyzed syllabi between 2004 and 2019 ($N = 478{,}233$).

Before conducting text analysis of syllabi, we pre-processed the data in three steps. First, we re-classified the 61 disciplines into five broad fields: arts and humanities, engineering and technology, medicine and health sciences, natural sciences, and social sciences. (Details of this categorization can be found in Supplementary Table S1.) Among 62 disciplines, we excluded "Basic Skills" because it does not have a strong disciplinary orientation. All syllabi uploaded to Open Syllabus were categorized into one of these 61 disciplines. Newly emerged interdisciplinary courses, such as those focusing on digital humanities or bioinformatics, were not the exception. These new courses were often sorted into a discipline aligned with their substantive interests. For instance, digital humanities classes were classified under English literature, while bioinformatics classes were classified under biology. By observing the temporal patterns across these broad fields, we highlighted the major changes in interdisciplinary education.

Second, we controlled the number of syllabi in the dataset by year. As more and more universities started sharing their syllabi online, the number of available ones increased. For example, the number of syllabi in 2019 was six times higher than 2004 (see Supplementary Fig. S1). To mitigate the influence of sample size on temporal patterns, particularly in the topic model, we randomly sampled 30,000 syllabi per year, resulting in a total of 480,000 syllabi between 2004 and 2019. If we use the raw data without sampling, the topic model will reflect more recent topics than earlier ones. Since our main analytical strategy involved comparing temporal patterns of interdisciplinarity in syllabi, we minimized confounding factors as much as possible through this sampling process. The sampling process helped us fairly observe the temporal trend without being biased towards recent periods that have the larger volume of data. Lastly, we filtered out syllabi from non-U.S. universities (1767 syllabi, 0.4%), which made the final dataset of 478,233 syllabi.

Syllabi were not equally distributed in five broad fields as well. In Fig. 1, we showed that the largest broad field, social sciences, has about seven times more syllabi than the smallest broad field, medicine and health sciences. However, we did not go through the additional sampling process to adjust the imbalance in broad field. It may affect how the topic model captures patterns in detail depending on the broad field, but since we group these topics by broad field later, the issue of different resolution will have a minimal effect on our results. In this case, we chose to use the data as they are as much as possible.

Figure 1 presents descriptive statistics of the final dataset. Among the five broad fields, social sciences account for the largest share of syllabi, followed by arts and humanities, natural sciences, engineering and technology, and medicine and health sciences. By degree level, 76.2% of syllabi are from undergraduate courses, with lower- and upper-division classes almost evenly split, and 24% from graduate courses. Regionally, the South contributes the most syllabi, followed by the Midwest, West, and Northeast. In terms of university type, 64.5% come from private universities and 28.6% from public universities.

Third, we pre-processed the text data through multiple steps. Using the spaCy package (v.3.7) in Python, we tokenized the contents of course titles and descriptions. For this process, we employed en_core_web_trf, its highest-accuracy transformer-based model for English. Then, we performed "part-of-speech tagging" to classify tokens as nouns, adjectives, or verbs and retained only their base forms through lemmatization. Lastly, we took into account bigrams to combine words often used together, such as in "decision making", "public speaking" or "criminal justice." After checking multiple thresholds (50, 100, 150, and 200), we defined bigrams as two words that co-occur 100 times or more in course titles and descriptions, yielding the most reliable set. We then combined these two words into a single token, creating 6,128 bigrams from our data.

Methods. As the significance of interdisciplinary research has been highlighted, measures of interdisciplinarity have largely been developed. Scientific articles are often the empirical site where interdisciplinarity is measured as an outcome of interdisciplinary research. Naturally, bibliometrics provide tools to measure interdisciplinarity in academic articles. There are two common approaches of measuring interdisciplinarity in bibliometrics: structural relationships and spatial distances (Wagner et al., 2011). The first set of measures uses relational information from academic articles, such as collaboration or citation networks (e.g., Schummer, 2004; Klein, 2008; Levitt and Thelwall, 2008). The second set of measures locates academic articles in a semantic space and calculates the distance between them. In this approach, interdisciplinarity is measured in three dimensions: variety (number of categories), balance (evenness of distribution), and disparity or similarity (degree of difference) (Wagner et al., 2011). As natural language processing techniques have evolved and become available in public datasets, researchers earn stronger tools with which to employ distance-based methods (e.g., Xiang et al., 2025).

We relied on previous developments in measuring interdisciplinarity in academic articles. Since our data, syllabi, lack information on co-teaching or reference lists, applying the structural relationship approach was not suitable. Therefore, we focused on measuring interdisciplinarity using spatial distances as a tool. We tested the interdisciplinarity of course syllabi using three approaches: lexical, topical, and pedagogical composition. The lexical approach measures the similarity of term frequency distribution to determine how *similar* broad fields are to each other. The topical approach measures the *balance* of distribution to determine interdisciplinarity. Lastly, the pedagogical approach analyzes not the course contents, but the types of intellectual activities pursued by lecturers. The stable composition of these three measures within a discipline over time shows persistence of an intradisciplinary curriculum, while changes suggest shifts toward interdisciplinarity. We explain each approach in the following subsections.

Lexical composition. To compare the lexical composition across broad fields, we used the distribution of tokens from the course title and description by year. From the processed text data described above, we selected only nouns and adjectives because these parts of speech were the most accurate representation of course content. Subsequently, we compiled the occurrences of each extracted token by broad field and year, and created the frequency distribution. Then, the similarity between these distributions was quantitatively assessed using cosine similarity, a metric for measuring interdisciplinary lexical similarity. Cosine similarity is a widely used metric that measures the similarity of two vectors by computing the cosine of the angle between the vectors. This measure is particularly useful compared to other measures such as Euclidean distance or Jaccard similarity when you compare two vectors with different sizes. For example, if you compare two vectors, (1, 2, 3) and (2, 4, 6), they have the same pattern except the size. Cosine similarity of these two vectors is 1, meaning that they are perfectly matched. In contrast, when we calculate the Euclidean distance between these two, it is a square root of fourteen. Since our term frequency distributions have different sizes depending on the size of broad fields, we chose the measure that can calculate similarity regardless of the size.

With cosine similarity, we compared how similar the token frequency distributions were across different categories within the same year, and checked if these similarities held over time. This approach helped us see simultaneously whether the use of popular tokens had changed within and across academic fields. By doing this, we tracked the interdisciplinarity of academic content that evolved or stayed the same across different broad categories and through the years.

Topical composition. In addition to counting token occurrences, we compared the topical composition of syllabi within and across broad fields over time. To identify the topics within the syllabi, we applied the Structural Topic Model (STM), which has been popularly used for distilling topics from various types of documents, such as open-ended survey responses and academic article abstracts (Hannigan et al., 2019; Hofstra et al., 2020; Roberts et al., 2014). Similar to our lexical analysis, we only selected nouns and adjectives as they represent the core concepts in scientific knowledge. The STM is a natural language processing technique based on unsupervised learning (Roberts et al., 2014). Unsupervised learning means the model has no prior knowledge of what the topics should be; it only observes topics based on the pattern of word co-occurrence within documents. Then, the model summarizes the given texts as a composition of latent thematic dimensions. In simple terms, when words often co-occur within documents, the model groups them into a latent thematic dimension or topic. When those words are observed in a document, the model assigns a higher probability that the document will be classified into the topic. This idea of STM is matched with how previous research conceptualizes scientific knowledge, particularly when they use natural language processing techniques (Hofstra et al., 2020; Cheng et al., 2023; Key and Sumner 2019). The final STM model provides two sets of findings. The first set is a list of topics that most optimally describe the corpus, along with keywords per topic. The second set is a list of documents (in this case, syllabi) represented by a mixture of the provided topics, each with a weight.

Using our tokenized text data, we implemented the STM with 15 topics. The number of topics was chosen to maximize semantic coherence—where higher semantic coherence means more coherent topics—and minimize exclusivity residuals, where lower exclusivity residuals indicate more exclusive topics. By comparing these two measures and manually reviewing the results, we determined that 15 topics were the most optimal (see Supplementary Figs. S2 and S3 online for more information on measures and diagnostic values.) The keywords and portion of 15 topics are shown in Fig. 2. Since the STM algorithm sorts keywords into topics in a way that optimally allocates terms by topic, the resulting topics may not perfectly align with human perception. For example, the term "forensic" in Topic 7 does not align with the other seemingly relevant terms related to mathematics in the same topic. Although there are a few exceptions, we use this result as is instead of adding human judgment to the model because authors' expertise is limited and/or biased and cannot span the entire field of science.

With these fifteen topics, we allocated each topic to one of the five broad fields based on the field that predominantly represented the topic. To determine the field, we analyzed the overall topic distribution across the five fields, and identified the field that discussed the topic most extensively in 2004. For example, Topic 5 was categorized as an arts and humanities topic because this topic accounted for 23% of arts and humanities content in 2004, compared to only 1.2% in social sciences, 1.7% in natural sciences, 0.6% in engineering and technology, and 1.1% in medicine and health sciences. Following this criterion, we found three topics associated with arts and humanities (3, 5, 12), two with engineering and technology (10, 13), one with medicine and health sciences (4), three with natural sciences (1, 7, 8), and four with social sciences (2, 9, 11, 14). We excluded Topics 6 and 15 from the analysis due to their lack of clear correspondence with established academic disciplines. Topic 15 is borderline because the list of keywords includes arts and humanities keywords, such as *moral* and *philosophy*, but also stop words such as *much*, *thing*, and *many*. To determine whether Topic 15 is irrelevant, we checked additional keywords beyond the ten shown in Fig. 2. These keywords include *different*, *view, mind, insight, philosopher, sense, thought, deep, reason*, and *one*. Based on this list, we decided that Topic 15 is too general to categorize into one broad field. Also, there was one exception: Topic 2. The keywords representing Topic 2 include keywords such as *education*, *school*, *teaching*, and *curriculum*. Although this indicates that Topic 2 relates to educational themes and that its broad field is the social sciences, this topic most stood out in medicine and health science in 2004, at 11%. However, we assigned this topic to the social sciences, which includes education, because Topic 2 occupied a comparable portion (10%) in 2004 and was more closely related in terms of keywords. Lastly, we checked the validity of our topic categorization by examining the thirty syllabi with the largest proportion of each topic. We confirmed that all of the top thirty syllabi are from disciplines within the assigned broad field.

With the topic model results, our main goal of the analysis was to detect shifts in the content of each broad field, thus providing

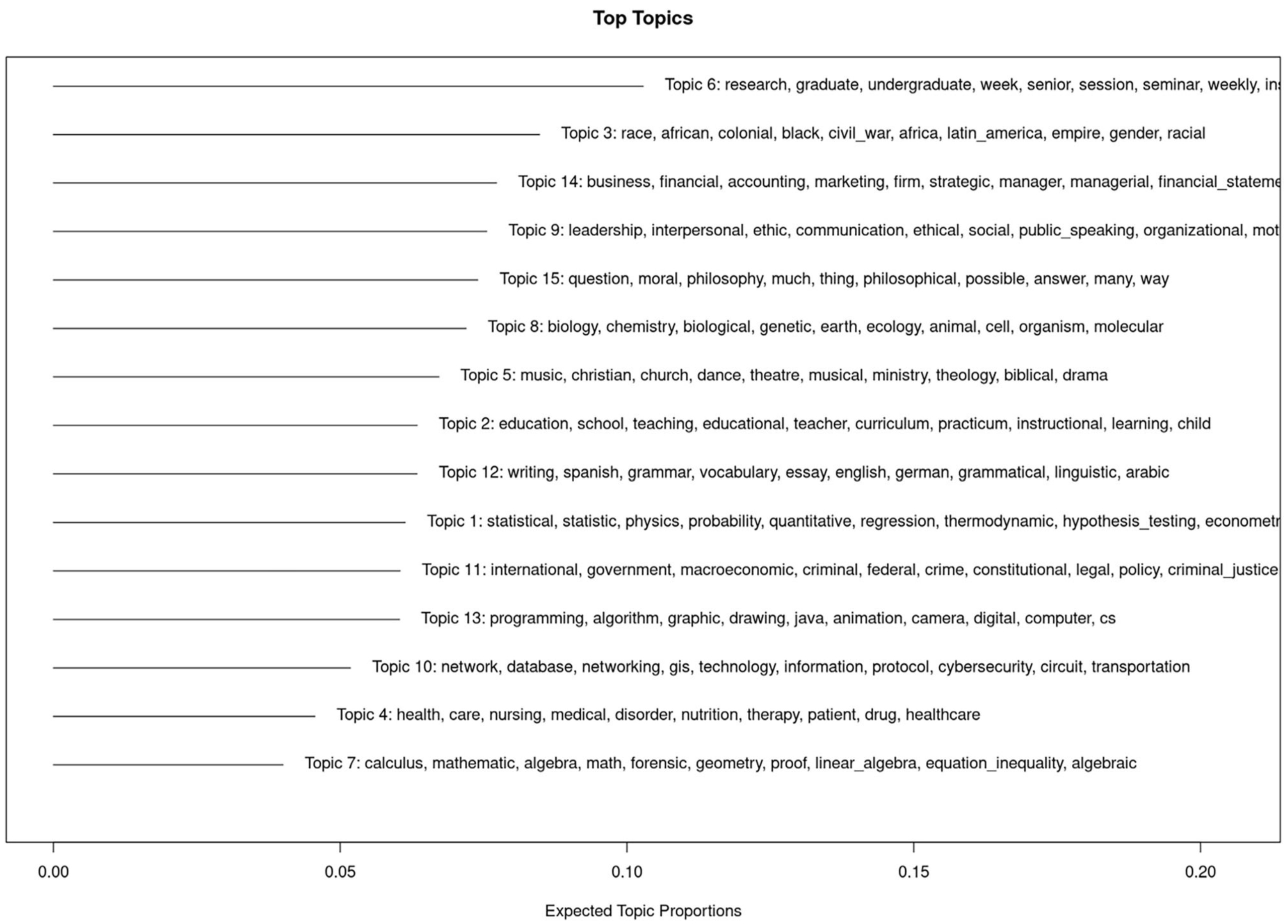

Fig. 2 The list of 15 topics from sourced syllabi. The list of words next to the topic number indicates the top words selected by the FREX (frequency and exclusivity) score for each topic.

insights into the evolution of academic fields. This structured allocation allows for a focused analysis on the representation of academic content within syllabi, facilitating a nuanced understanding of disciplinary interrelations and content distribution.

Next, we grouped the initial topic distribution within each syllabus to align with the newly assigned broad categories, examining these groupings' distribution across different categories and years. To assess the variations in these distributions, we employed the Herfindahl–Hirschman Index (HHI), a metric traditionally used in economics and finance to gauge the level of market concentration and, by extension, the competitive landscape of an industry. By applying the HHI to academic topic distributions, we quantified the concentration and diversity of disciplinary content within and across academic disciplines over time. As a pilot study, we manually selected ten interdisciplinary syllabi and ten discipline-based syllabi used in 2019. Then, we calculated the HHI to validate our approach and found that the HHI of the interdisciplinary classes was approximately one-third that of the discipline-based classes, and statistically significant with .05 alpha level. This indicates that the topics are more spread out among the interdisciplinary syllabi. More details are included in Supplementary Figs. S4 and S5 online.

Verb composition. Lastly, we focused on whether the curricula across broad disciplines have shifted toward pursuing more complex educational goals necessary for interdisciplinary research. We analyzed the verbs used in syllabi to infer the pedagogical strategies offered by instructors. We used Bloom's taxonomy, a well-known framework for classifying educational goals (Krathwohl, 2002), to distinguish different orientations in educational curricula. This taxonomy ranks cognitive skills from basic to complex: *remember*, as the most basic skill, followed by *understand*, *apply*, *analyze*, *evaluate*, and finally *create* as the most complex skill. The framework also associates commonly used action verbs with each level of cognitive complexity. Since its initial development in 1956, Bloom's taxonomy has been modified multiple times to reflect ongoing changes in pedagogical approaches and language itself.

To reflect these changes, we incorporated action verbs from Northeastern University (Northeastern University, Accessed 2025) and added verbs from the revised Bloom's taxonomy from the State University of New York at Buffalo (The State University of New York at Buffalo, Accessed 2025), and the University of Utah (The University of Utah, Accessed 2025) to make the list as comprehensive as possible. We list all verbs and their classification into six categories in Supplementary Table S2 online.

We matched the action verbs used in syllabi with the corresponding cognitive skills from Bloom's taxonomy. We extracted only the verbs using part-of-speech tagging from the same corpus we analyzed earlier. We then investigated how the focus of education had shifted by looking at the distribution of cognitive skills in syllabi, broken down by year and broad field.

Among the 258 words in our taxonomy, 90 were found to fit into multiple skill categories, with some fitting up to five categories (for more details, see Supplementary Table S3 online). For example, the verb "explain" could correspond to the skills of *understand*, *apply*, *analyze*, *evaluate*, and *create* in learning objectives. We reviewed each word's meaning and concluded that

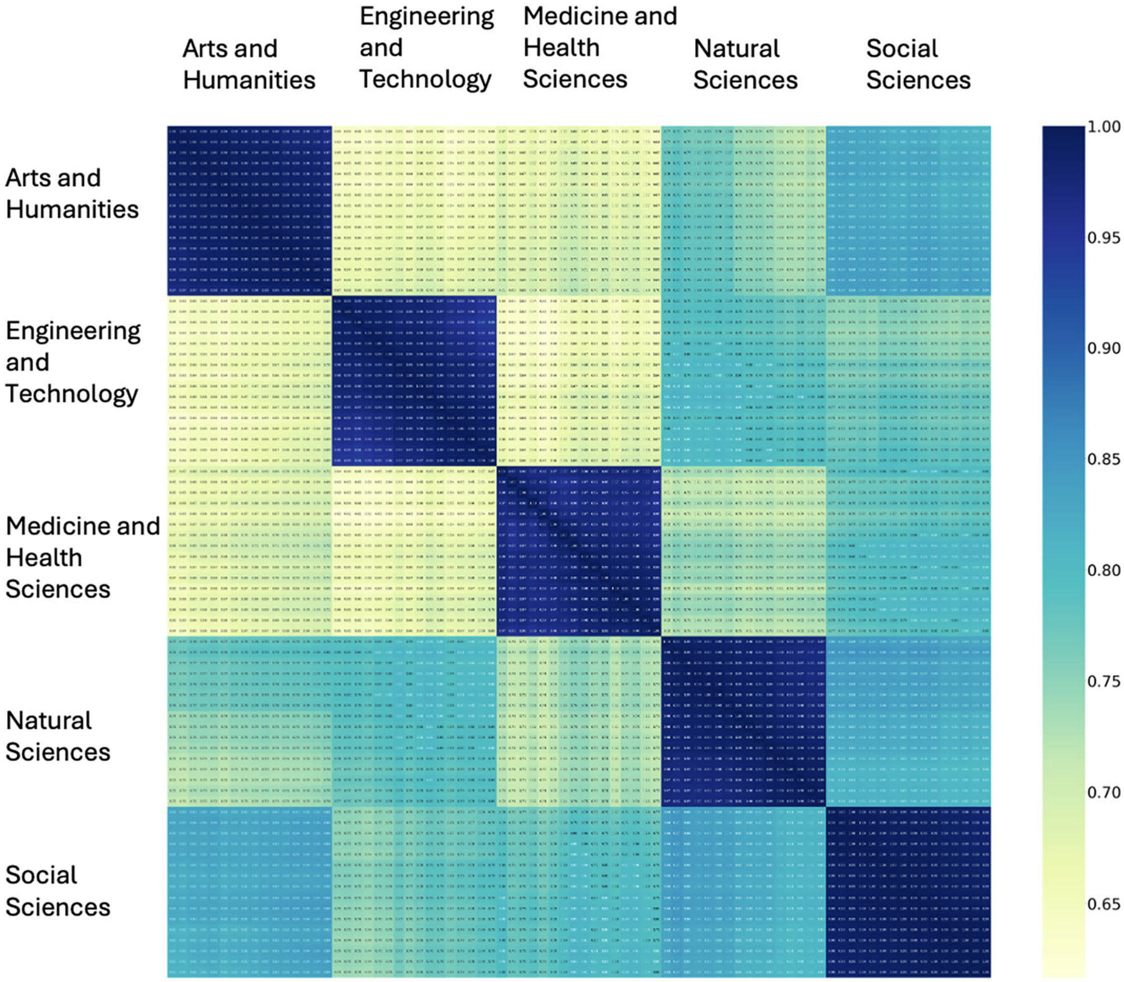

Fig. 3 Cosine similarity of token frequency distribution by broad fields and years.

many were broad enough to be categorized into multiple levels. To address concerns about the over-representation of words that appear in multiple categories, we introduced a weighting system. Words that appeared in two categories were assigned a weight of 0.5 per skill, those appearing three times received a weight of 0.33 each, those appearing four times received 0.25 each, and those appearing five times received 0.2 each. For instance, when the word "explain" appears in a syllabus, rather than assigning a weight of 1 to each of the skills *understand*, *apply*, *analyze*, *evaluate*, and *create*, a weight of 0.2 was assigned. Using these weighted values, the proportion of each skill was then calculated.

Results

Temporal changes in lexical composition. Figure 3 illustrates the changes in syllabus terminology between 2004 and 2019, as measured by the cosine similarity of term frequency distributions. Each large square represents the relationship between two broad fields, divided into a 16×16 grid, where each small square corresponds to a specific year. The cosine similarity is 1 when two vectors perfectly match, 0 when they are irrelevant to each other, and -1 when they perfectly match in an opposite way. The color intensity indicates the level of similarity, with darker colors showing higher similarity. Because terminology evolves over time, the terms used in 2004, for example, are not identical to those used in 2019, making the cosine similarity matrix asymmetric. For each broad field and year in a row, we compute the cosine similarity with the corresponding year in a column.

The overall cosine similarity is relatively high at 0.60 or above, indicating that syllabi generally use similar terms. It is not surprising to find the generally high cosine similarity, because syllabi serve the same purpose, introducing courses to students. Also, we see a straightforward temporal pattern in Fig. 3. The color consistency within each large square indicates that the relationships between broad fields have remained stable over the 16 years studied. For example, terms in the arts and humanities are consistently more similar to social sciences than to engineering and technology. Meanwhile, engineering and technology tend to share more terminology with natural sciences than with either arts and humanities or medicine and health sciences. Social sciences maintain relatively high similarity across all fields, at around 0.85.

The consistent color patterns also suggest minimal changes in term usage across fields over time. The lack of noticeable color variation in a large square, which represents a 16-year span, confirms that the distinct terminology of each broad field has remained relatively unchanged over the years.

Temporal changes in topic composition. Figure 4 shows a series of stacked bar graphs illustrating the distribution of topics in syllabi across broad fields from 2004 to 2019. By combining the topic composition of all syllabi, we can calculate the collective share of the topic over time. The colors in the stacked bar graphs represent the broad fields associated with each topic. Naturally, topics related to the arts and humanities make up the highest proportion within their respective field, and this pattern applies to other fields as well. If the composition of topics has dynamically

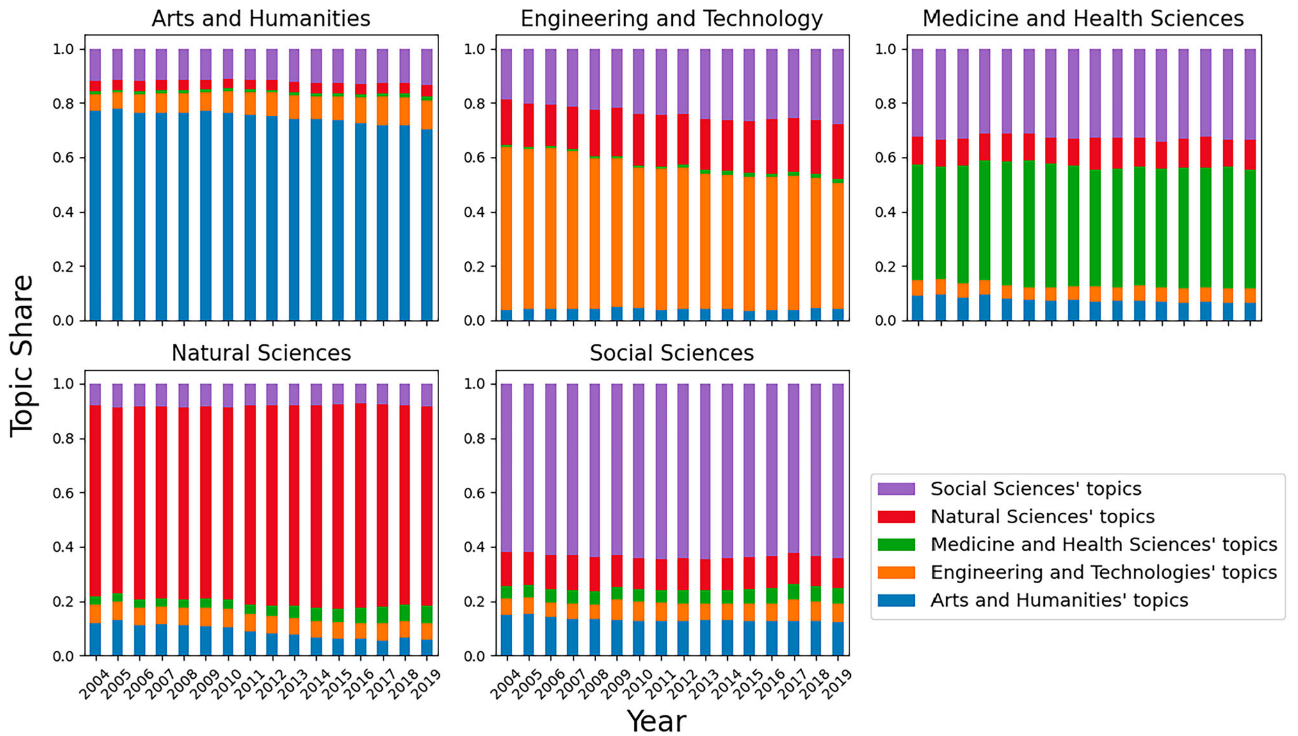

Fig. 4 Topic distribution of all syllabi across broad fields between 2004 and 2019.

shifted to reduce their main topic proportion, it indicates that the field has become more interdisciplinary over time.

The actual patterns we observe in Fig. 4 are, in fact, the opposite. The composition of topics in medicine and health sciences, natural sciences, and social sciences remains stable over the years. In arts and humanities, although arts and humanities topics remained dominant during the observed period, their share gradually decreased from 77.08% in 2004 to 70.01% in 2019. This decline in dominance has been offset by an increase in engineering and technology topics, which rose from 6.1% in 2004 to 10.9% in 2019. The broad field that has gone through the most rapid change is engineering and technology. The share of engineering and technology relevant topics is 60.2% in 2004, but it decreases to 46.2% in 2019. The reduced share of engineering and technology was replaced by the increased share of social science topics (18.8 to 27.9%) and natural science topics (16.6 to 20%). We tested the robustness of our results by considering only the most prominent topic per document and then recreating the Fig. 4 (Supplementary Fig. S6 online). While the specific values vary slightly, the general pattern remains with the one described in the main text.

In Fig. 5, we summarize the patterns identified in Fig. 4 by calculating the HHI index over time, which measures the concentration of topics. A high HHI index indicates a higher concentration, meaning that a small number of topics dominate the distribution of syllabi topics. This analysis supports the patterns observed earlier, showing that the HHI index in the natural sciences (red), social sciences (purple), and medicine and health sciences (green) remains stable during the observed period. Conversely, the dominance of topics in the arts and humanities, as well as in engineering and technology, decreases over time, signaling the development of a more interdisciplinary curriculum.

Temporal changes in educational goals. So far, we have examined the temporal changes in the substantive content of syllabi. However, the role of higher education—extends beyond simply delivering content. Nearly three decades ago, Barr and Tagg highlighted the importance of shifting the educational paradigm from 'instruction' to 'learning,' emphasizing the role of college as a place for discovering and constructing new knowledge rather than consuming the existing knowledge (Barr and Tagg, 1995). They argued that transforming education into "learning" can address new and previously unknown challenges most effectively. Interdisciplinary research aligns with this perspective by encouraging researchers to think beyond traditional disciplinary boundaries and develop creative solutions.

In this context, we examine whether the educational philosophy in both undergraduate and graduate programs highlights the creation of new knowledge. Using Bloom's taxonomy categorizing educational goals based on action verbs, we assess the level of educational complexity. The taxonomy starts with the lowest level of learning goals, *remember*, followed by *understand*, *apply*, *analyze*, *evaluate*, and *create*. Figure 6 presents the proportion of action verbs in syllabi, categorized according to Bloom's six levels. If universities are preparing future researchers through teaching programs to engage in interdisciplinary research, we would expect the syllabi to broaden their educational goals to place greater emphasis on creativity, as Weingart (2014: 4) emphasized that "the organization of science as the basis for creative human action should shift more and more to interdisciplinary approaches."

The results are displayed in Fig. 6 as stacked bar graphs showing the share of action verbs in the syllabi corpus for each broad field. The composition of verb types remains surprisingly stable between 2004 and 2019. Overall, the most prevalent types of knowledge are *apply* and *understand* throughout this period. We do not observe an increasing emphasis on educational goals associated with *create* or *evaluate*. We perform the same analysis by degree level to observe whether there have been any changes in graduate programs, which are supposed to be more research-oriented compared to the undergraduate programs. Although graduate programs use more complex pedagogical strategies, such as "create" or "evaluate," than undergraduate, the proportion of these strategies has remained stable (Supplementary Information Fig. S7 online).

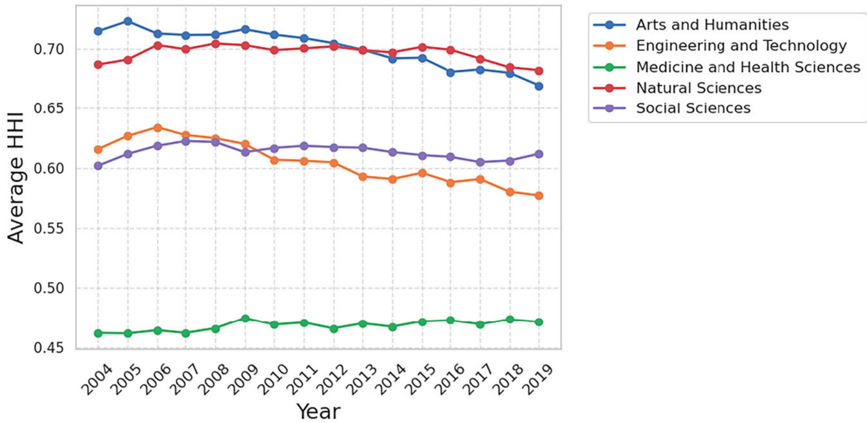

Fig. 5 The average Herfindahl–Hirschman Index (HHI) of syllabus topic composition in each broad field between 2004 and 2019.

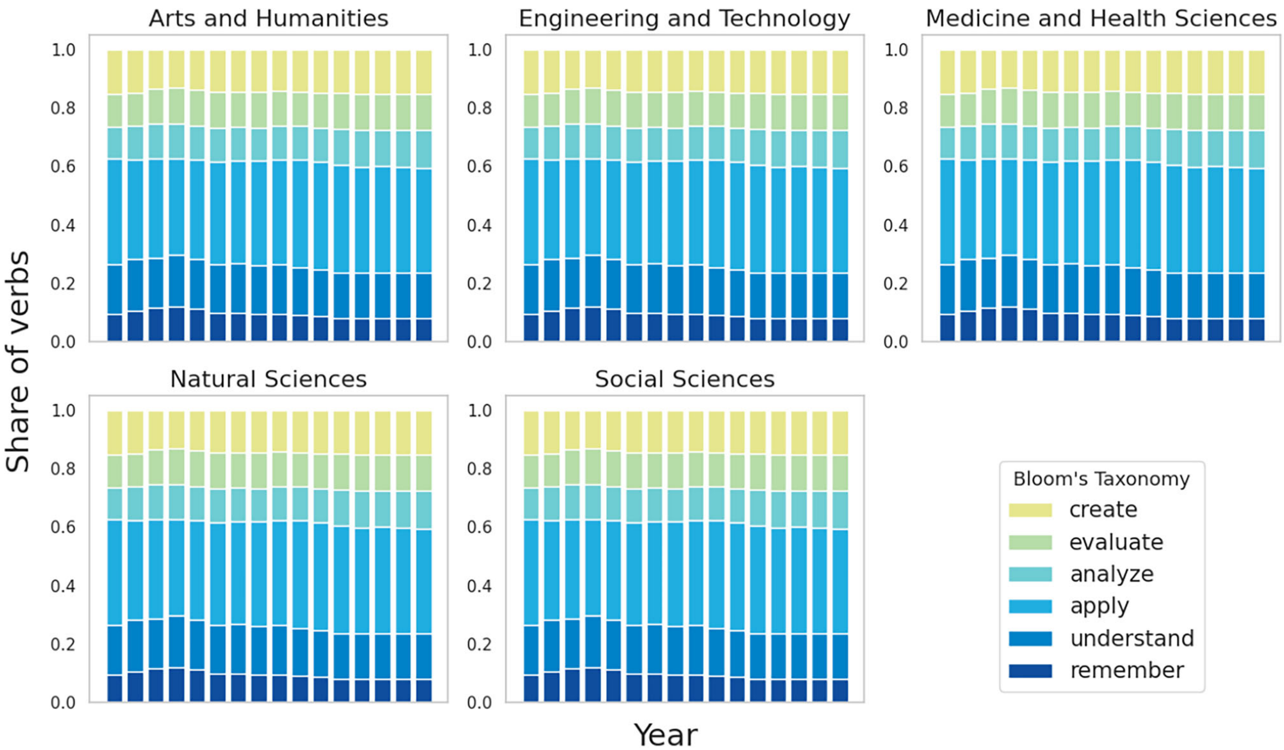

Fig. 6 Changes in the proportion of Bloom's taxonomy word levels in "Learning Outcomes" from 2004 to 2019.

Discussion and conclusion

Although interdisciplinary research has garnered significant attention from researchers, policymakers, and university institutions—prompting scrutiny of its effectiveness—the question of whether our educational environment is ready for interdisciplinary education has received little attention. This is a crucial problem, considering the close relationship between education and research in the higher education. As one way of investigating interdisciplinary education, we analyzed the syllabi of undergraduate and graduate programs at universities in the United States, using syllabi archived in the Open Syllabus online database from 2004 to 2019 and applying natural language processing techniques. Our findings revealed that the terms used in university classes strongly maintain disciplinary boundaries, rather than integrating diverse knowledge across courses. The substantive topics discussed in broad fields also remained stable over the observed 16-year period, reinforcing disciplinary distinctions. If there are any changes, the field of engineering and technology has been the quickest to move to interdisciplinary research by incorporating social science and natural science knowledge, while the arts and humanities follow by integrating engineering knowledge. Lastly, we found that the educational goals within broad disciplines have remained largely stable, showing little progress toward higher-level goals such as critically evaluating existing knowledge or creating new knowledge. In summary, despite the increasing prevalence of interdisciplinary research collaborations in universities, interdisciplinary education seems to still be largely rhetorical. This suggests that additional institutional efforts are needed to bridge the gap between interdisciplinary research and education, to establish innovative nexus between them.

Our findings suggest that although university programs are intended to bridge the gap between the consumers (i.e., education) and producers (i.e., research) of knowledge, institutional efforts to promote interdisciplinary research have not been effectively operationalized within the teaching and learning practices, as evidenced, at least, by course syllabi. University courses serve as significant foundation for preparing future researchers, and missing this opportunity hinders the goal of advancing an interdisciplinary agenda. Integrating interdisciplinary research into undergraduate and graduate classroom is clearly challenging, as universities maintain rigid department structures in their educational programs. This may indicate that professed interdisciplinarity in university research is, in fact, institutionally decoupled from universities' everyday teaching practices. This decoupling may be driven by multiple organizational factors operating simultaneously, including the slow turnover of faculty members, inadequate institutional support for interdisciplinary teaching, and the lower prioritization of teaching efforts relative to research excellence in contemporary higher education institutions.

Another factor that may have slowed the integration of an interdisciplinary agenda into the universities' teaching programs is the negative perception of the benefits of interdisciplinary education. Since both undergraduate and graduate coursework are critical for mastering the basics of disciplinary knowledge, interdisciplinary approaches may be viewed as potentially hindering this training by offering only a shallow combination of different fields. Indeed, as previous literature suggests (Daniel et al., 2022; MacLeod, 2018), effective interdisciplinary research is challenging to achieve and prone to failure, which increases the difficulty of incorporating it into educational programs. Nonetheless, it is still surprising how little US universities' teaching programs have collectively adjusted their educational goals to incorporate interdisciplinarity into their classrooms.

The most notable change in the middle of this otherwise stable education system is found in the fields of engineering and technology. Driven by advancements in artificial intelligence, engineering and technology have attracted significant attention and resources over the past two decades (Bogost, 2024). These fields expand their disciplinary interests by garnering attention from the social and natural sciences. Interestingly, arts and humanities, a relatively low-resource area, is also becoming more interdisciplinary. Arts and humanities courses have included more materials from engineering and technology, fields that seem far from being integrated. Future research on syllabi could examine the different motivations and mechanisms of high- and low-resource fields in pursuing interdisciplinary research.

Our research is significant as one of the few empirical examinations of interdisciplinary education in universities that uses big data and text analysis. At the same time, our research has limitations and opens up numerous possibilities for applying natural language processing techniques. We list the notable limitations and possible future research to address these limitations. First, our dataset was not a random sample of United States universities, making it difficult to generalize the results. Our descriptive statistics revealed that our data were biased toward private universities, social science courses, and southern regions. If universities have different levels of institutional force in promoting interdisciplinary research based on type or regional characteristics, this could lead to an underestimation or overestimation of the temporal pattern of interdisciplinary education. Second, our data did not include reading lists, which could provide valuable insight into interdisciplinary education. Similar to how citation analysis is popular for measuring interdisciplinary research (Wagner et al., 2011), reading materials in syllabi could also be an invaluable resource for understanding interdisciplinary education. Collecting reading list data and remeasuring interdisciplinarity could be a promising future direction for understanding the difference between topic- and knowledge-based interdisciplinarity (Xiang et al., 2025). Third, rather than focusing on students' consumption patterns, we have focused on the interdisciplinary approach reflected in the courses provided by departments. By either fostering students' voluntary interest or mandating official courses, each university may have encouraged students to engage in interdisciplinary coursework, thereby exposing them to knowledge from various disciplines. This possibility has not been considered in this paper and suggests a direction for future research on changes in university program course requirements. Fourth, our time span is limited to sixteen years, which may be too short to evaluate the institution's efforts to change its educational program. Given the organizational inertia of interdisciplinary research to achieve its goals (Weingart, 2013), it is realistic to extend the time period to observe meaningful changes.

Data availability

We provide the necessary code to replicate the results on this Github page: https://github.com/chooonsik/OS. The datasets are now not publicly open, and need to be requested via Open Syllabus webpage (https://www.opensyllabus.org).

Received: 10 February 2025; Accepted: 20 October 2025;
Published online: 26 November 2025

References

Ashwood L, Harden N, Bell MM, Bland W (2014) Linked and situated: grounded knowledge. Rural Socio 79(4):427–452. https://doi.org/10.1111/ruso.12042

Barr RB, Tagg J (1995) From Teaching to Learning —A new paradigm for undergraduate education. Change 27(6):12–26. https://doi.org/10.1080/00091383.1995.10544672

Bear A, Skorton, D (2019) The world needs students with interdisciplinary education. *Issues in Science and Technology*. https://www.jstor.org/stable/26948993

Bell, M (2004) *Farming for us all : practical agriculture & the cultivation of sustainability*. Pennsylvania State University Press

Berman EP (2012) Explaining the move toward the market in US academic science: how institutional logics can change without institutional entrepreneurs. Theory Soc 41(3):261–299

Biasi B, Ma S (2022) *The Education-Innovation Gap* (No. w29853). Natl Bureau Econ Res. https://doi.org/10.3386/w29853

Bogost I (2024) Universities Have a Computer-Science Problem. The Atlantic. https://www.theatlantic.com/technology/archive/2024/03/computing-college-cs-majors/677792/

Bourrier K, Thelwall, M (2020) The social lives of books: reading Victorian literature on Goodreads. J Cult Analyt 5(1). https://doi.org/10.22148/001c.12049

Bromham L, Dinnage R, Hua X (2016) Interdisciplinary research has consistently lower funding success. Nature 534(7609):684–687. https://doi.org/10.1038/nature18315

Cheng M, Smith DS, Ren X, Cao H, Smith S, McFarland DA (2023) How new ideas diffuse in science. Am Socio Rev 88(3):522–561

Daniel KL, McConnell M, Schuchardt A, Peffer ME (2022) Challenges facing interdisciplinary researchers: findings from a professional development workshop. PloS ONE 17(4):e0267234. https://doi.org/10.1371/journal.pone.0267234

DiMaggio PJ, Powell WW (1983) The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. Am Socio Rev 48(2):147–160

DiMaggio PJ, Powell WW (1991) The new institutionalism in organizational analysis (Vol. 17). University of Chicago Press Chicago, IL

Frodeman R, Mitcham C (2007) New directions in interdisciplinarity: broad, deep, and critical. Bull Sci Technol Soc 27(6):506–514. https://doi.org/10.1177/0270467607308284

Frodeman R, Klein JT, Dos Santos Pacheco, RC (eds.) (2016) The oxford handbook of interdisciplinarity (2nd ed.). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198733522.001.0001

Gibbons M (1994) The new production of knowledge: The dynamics of science and research in contemporary societies. Sage

Gibbons M (2000) Mode 2 society and the emergence of context-sensitive science. Sci \ Public Policy 27(3):159–163

Gim G, Yun J, Lee SH (2025) Quantifying interdisciplinary synergy in higher STEM education. EPJ Data Sci 14:56

Hannigan TR, Haans RFJ, Vakili K, Tchalian H, Glaser VL, Wang MS, Kaplan S, Jennings PD (2019) Topic modeling in management research: rendering new theory from textual data. Acad Manag Ann 13(2):586–632. https://doi.org/10.5465/annals.2017.0099

Hofstra B, Kulkarni VV (2020) The diversity–innovation paradox in science. Proc Natl Acad Sci USA. https://www.pnas.org/doi/abs/10.1073/pnas.1915378117

Holt R, Woods P, Ferreira AS, Bardarson H, Bonanomi S, Boonstra W, Butler W, Diekert F, Fouzai N, Holma M, Kokkalis A, Kvile K, Macdonald J, Malanski E, Nieminen E, Ottosen KM, Pedersen MW, Richter A, Rogers L, Yletyinen J (2017) Avoiding pitfalls in interdisciplinary education. Clim Res 74:121–129. https://doi.org/10.3354/CR01491

Jacobs JA, Frickel S (2009) Interdisciplinarity: a critical assessment. Annu Rev Sociol 35(1):43–65. https://doi.org/10.1146/annurev-soc-070308-115954

Javadian Sabet A, Bana SH, Yu R, Frank MR (2024) Course-skill Atlas: a national longitudinal dataset of skills taught in U.S. higher education curricula. Sci Data 11(1):1086. https://doi.org/10.1038/s41597-024-03931-8

Key EM, Sumner JL (2019) You research like a girl: gendered research agendas and their implications. Polit Sci Polit 52(4):663–668

Klaassen RG (2018) Interdisciplinary education: a case study. Eur J Eng Educ 43(6):842–859. https://doi.org/10.1080/03043797.2018.1442417

Klein JT, Newell WH (1997) Advancing interdisciplinary education. In: Gaff JG & Ratcliff JL (eds.) Handbook of the undergraduate curriculum. Association of American Colleges and Universities. https://www.academia.edu/download/51251765/Advancing_Interdisciplinary_Studies20170108-20141-1hj8rou.pdf

Klein JT (2008) Evaluation of interdisciplinary and transdisciplinary research: a literature review. Am J Prevent Med 35(2):S116–S123

Klein JT (2010) A taxonomy of interdisciplinarity. Oxf Handb Interdiscip 15(6):15

Kleinman D, Feinstein NW, Downey G, Peterson S, Fukada C (2017) Hybrid experiments in higher education. Sci Technol Human Values. 016224391773736. https://doi.org/10.1177/0162243917737365

Krathwohl DR (2002) A revision of bloom's taxonomy: an overview. Theory into Pract 41(4):212–218. https://doi.org/10.1207/s15430421tip4104_2

Levitt JM, Thelwall M (2008) Is multidisciplinary research more highly cited? A macrolevel study. J Am Soc Inf Sci Technol 59(12):1973–1984

Lindvig K, Lyall C, Meagher LR (2019) Creating interdisciplinary education within monodisciplinary structures: the art of managing interstitiality. Stud High Educ 44(2):347–360. https://doi.org/10.1080/03075079.2017.1365358

MacLeod M (2018) What makes interdisciplinarity difficult? Some consequences of domain specificity in interdisciplinary practice. Synthese 195(2):697–720. https://doi.org/10.1007/s11229-016-1236-4

McGregor SLT (2017) Transdisciplinary pedagogy in higher education: transdisciplinary learning, learning cycles and habits of minds. In Transdisciplinary Higher Education p 3–16. Springer International Publishing. https://doi.org/10.1007/978-3-319-56185-1_1

Meyer JW, Rowan B (1977) Institutionalized organizations: formal structure as myth and ceremony. Am J Sociol 83(2):340–363

Northeastern University. "Course Learning Outcomes." Northeastern Center for Advancing Teaching and Learning Through Research, https://learning.northeastern.edu/course-learning-outcomes. (Accessed 11th Jan 2025)

Nowogrodzki A (2016) Mining the secrets of college syllabuses. Nature 539(7627):125–126. https://doi.org/10.1038/539125a

Nowotny H, McBee D, Leahey E, Downey GJ, Feinstein NW, Kleinman DL, Peterson S, Fukuda C, Smith-Doerr L, Croissant J, Vardi I, Sacco T, Paradis E, Kuper A, Panofsky A, Light R, Ilhan AO, Mody CCM, Reisch H, Cassidy A (2016) Investigating interdisciplinary collaboration: theory and practice across disciplines. https://scholar.google.com/citations?view_op=view_citation&hl=en&citation_for_view=hEo3m-8AAAAJ:9yKSN-GCB0IC

Open Syllabus. (2023) "Open syllabus Dataset Documentation." Open Syllabus. https://docs.opensyllabus.org/index.html. (Accessed 11 Jan 2025)

Roberts ME, Stewart BM, Tingley D, Lucas C, Leder-Luis J, Gadarian SK, Albertson B, Rand DG (2014) Structural topic models for open-ended survey responses. Am J Polit Sci 58(4):1064–1082. https://doi.org/10.1111/ajps.12103

Sá CM (2008) "Interdisciplinary strategies" in U.S. research universities. High Educ 55(5):537–552. https://doi.org/10.1007/s10734-007-9073-5

Schummer J (2004) Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. Scientometrics 59(3):425–465

The State University of New York at Buffalo. "Bloom's revised taxonomy." Office of Curriculum, Assessment, and Teaching Transformation at the State University of New York at Buffalo, https://www.buffalo.edu/catt/teach/develop/design/learning-outcomes/blooms.html. (Accessed 11 Jan 2025)

The University of Utah. "Bloom's taxonomy – revised for 21st-century learners." Martha Bradley Evans Center for Teaching Excellence at the University of Utah, https://cte.utah.edu/instructor-education/Blooms-Taxonomy.php. (Accessed 11 Jan 2025)

Townsend T, Pisapia J, Razzaq J (2015) Fostering interdisciplinary research in universities: a case study of leadership, alignment and support. Stud High Educ 40(4):658–675. https://doi.org/10.1080/03075079.2013.842218

Van Noorden R (2015) Interdisciplinary research by the numbers. Nature 525(7569):306–307. https://doi.org/10.1038/525306a

Vereijken MWC, Akkerman SF, te Pas SF, van der Tuin I, Kluijtmans M (2023) Undisciplining' higher education without losing disciplines: furthering transformative potential for students. High Educ Res Dev 42(7):1762–1775. https://doi.org/10.1080/07294360.2022.2156482

Wagner CS, Roessner JD, Bobb K, Klein JT, Boyack KW, Keyton J, Rafols I, Börner K (2011) Approaches to understanding and measuring interdisciplinary scientific research (IDR): a review of the literature. J Informetr 5(1):14–26

Weingart (2000) Interdisciplinarity: the paradoxical discourse. Practising Interdisciplinarity, 13–20. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Practising+interdisciplinarity#0

Weingart P (2013) The loss of trust and how to regain it: performance measures and entrepreneurial universities. Trust Univ 86:1–13

Weingart P, Padberg B (2014) University experiments in interdisciplinarity: Obstacles and opportunities. In Weingart P & Padberg, B (eds). Transcript Verlag. https://doi.org/10.1515/transcript.9783839426166

Weingart P (2014) Interdisciplinarity and the new governance of universities. In University Experiments in Interdisciplinarity. p 151–174. Transcript Verlag. https://doi.org/10.1515/transcript.9783839426166.151

Wilson A (2010) Knowledge power: Interdisciplinary education for a complex world. Routledge. https://doi.org/10.4324/9780203858035

Xiang S, Romero DM, Teplitskiy M (2025) Evaluating interdisciplinary research: disparate outcomes for topic and knowledge base. Proc Natl Acad Sci USA 122(16):e2409752122

Acknowledgements

We thank Ahram Moon for the careful feedback and encouragement on this article. This research was supported by the National Research Foundation of Korea (N01250609).

Author contributions

Y.H., B.K., J.J., and L.K. conceived the idea and designed the research. Y.H. and B.K. collected the data and performed the analysis. Y.H., B.K., and L.K. prepared the figures. Y.H., J.J., and L.K. wrote the main manuscript text. Y.H., B.K., J.J., and L.K. revised and approved the manuscript. J.J. and L.K. funded the research.

Competing interests

The authors declare no competing interests.

Ethical approval

Because this study does not involve human participants or their data, we do not obtain ethical approval.

Informed Consent

Because this study does not involve human participants or their data, we do not obtain informed consents.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-025-06126-7.

Correspondence and requests for materials should be addressed to June Jeon or Lanu Kim.