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Providing engineering education researchers and stakeholders with easy access to granular, disparate data sources

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Providing engineering education researchers and practitioners with easy access to disparate data sources

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***Abstract*—When addressing equity in engineering education, data from multiple disparate sources are needed to build a full picture of the state of participation. While some efforts exist to integrate these data within a specific domain, such as higher education clearinghouses, structure for data sharing agreements, and government initiatives like state longitudinal data systems, there is no larger effort to create a relatively easily accessible set of data that links data throughout the education ecosystem and beyond. Furthermore, practitioners and researchers are frequently limited in the time and data manipulation skills needed to unify these datasets on their own. This paper examines an ongoing effort to deploy a data visualization tool and associated dataset that unifies postsecondary education, general population, and engineering alliance data with the goal of improving the understanding of the landscape of engineering education and models of success in BPE at institutional, regional, and national levels of engineering education.**

***Index Terms*—Systems, user interfaces, data visualization**

I. Introduction

Equipping engineering education researchers, practitioners, and policymakers with granular longitudinal data allows them to understand the landscape, trends, and impacts of strategic broadening participation in engineering (BPE) initiatives both broadly and at their institutions. Achieving and sustaining BPE is a daunting challenge with known benefits [1]. Despite significant investments by the National Science Foundation (NSF), Black, Indigenous and other People of Color (BIPOC) & women remain underrepresented among engineering U.S. bachelor's and graduate degree recipients (Table I) [2], [3]. NSF-funded programs have seen localized success in effecting change in engineering education across the nation, but there is a need to scale and evaluate these successful practices using disaggregated data from multiple sources [5], [6].

To scale these initiatives, we must identify successful BPE practices in engineering education. In order to understand what constitutes a "successful BPE practice", it is not enough to only consider metrics for a single component of the engineering education ecosystem (such as degree completion rates). Nor is it enough to only be reactive to metrics that describe the population of engineering students at a single moment in time. If we are to usefully measure how well the engineering education ecosystem is serving the population, we must analyze the complete path of students from early education through employment, as in Figure 1. It may be helpful to go even further as well, by looking at current demographics to establish who the students of the future will be.

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Year	Total Pop.	Pct. BIPOC Pop.	Total Eng. Completions	Pct. BIPOC Completions
2014	45,620,629	38%	108,410	18%
2015	45,503,815	39%	113,117	19%
2016	45,281,433	39%	120,390	20%
2017	44,990,211	39%	127,592	20%
2018	44,774,728	39%	133,291	21%
2019	44,639,953	39%	138,248	21%
2020	45,044,715	40%	139,500	22%
2021	45,217,182	40%	139,600	24%
2022	45,662,139	41%	141,612	24%
2023	46,149,001	41%	140,073	25%

TABLE I
US Population aged 15–24 vs. engineering Bachelor's, Master's, and Doctorate completions

This holistic, longitudinal view allows us to establish ongoing trends in BPE (or lack thereof). Such trend analysis is important for two reasons. Firstly, because BPE efforts must be normalized against already-occurring trends in engineering education in order to establish their effectiveness. Secondly, because the goal of effective BPE initiatives is to influence and improve ongoing trends in engineering education, not just create one-off effects.

Once a holistic view is taken in this manner, we must establish what our measures of the health of engineering education are and in what pathways stage(s) they exist. This raises a deeply personal question for the education research discipline that must be answered so that we can better measure the performance of the engineering education system: *why* are we educating engineers? Is the ideal outcome a fulfilling career for each student? The production of a useful worker and their labor? Or something else entirely?

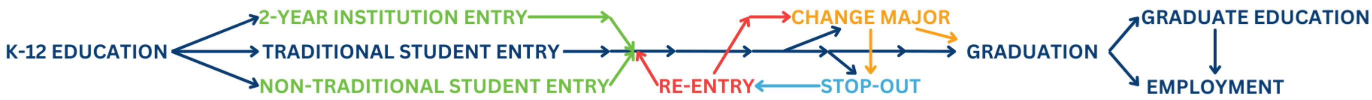

Fig. 1. A holistic view of student pathways through the engineering education ecosystem

These considerations demand access to granular longitudinal data; however there are several barriers to accessing such data [7]. These include the volume and currency of available data, skills required to interact with large data, and the disjointed nature of data that are available but not explicitly designed for use with one another. Furthermore, while relevant data are frequently accessible in pre-packaged national or state-level tables and reports, many researchers require more granular data at the institutional and/or discipline level in order to fully contextualize their work. This can introduce a prohibitive amount of labor into the act of retrieving data, and complicates the process of joining datasets that exist at different levels of granularity.

This paper examines an ongoing effort to make granular, highly relevant, but disjointed data accessible and easily digestible to researchers and stakeholders. This includes a tool designed to present easy access to and enhance inquiry into data sources, as well as an interactive data visualization tool bringing together data from several commonly used (but disjoint) sources.

II. Background

The Engineering PLUS[1] Alliance is an NSF INCLUDES[2] Alliance of higher education institutions organized to increase the number of BIPOC and women degree earners. NSF INCLUDES is a nationwide initiative designed to build U.S. leadership in STEM by increasing the participation of groups historically underrepresented in STEM [10]. To achieve these goals, Engineering PLUS proposed to scale research-based recruitment and retention strategies for BIPOC and women students. To do so, Engineering PLUS has partnered with various established alliances, such as NSF's Louis Stokes Alliances for Minority Participation, to access and utilize their experience, regional infrastructures, and influence.

The experience of these alliances is being leveraged through the establishment of several "regional hubs" (referred to as Hubs) [11]. These Hubs are intended to serve as a support system for participating institutions by providing and encouraging a collaborative network of stakeholders. There are currently three such hubs: one in the Northeastern U.S. (Massachusetts, Connecticut, and Rhode Island), one in the Midwestern U.S. (Ohio, Indiana, Michigan, Kentucky, Illinois, Wisconsin, and Minnesota), and the in-progress hub in the western U.S. The stEm Practitioners Enhancing Engineering Regionally (PEER) Academy is offered through the Hubs and presents an opportunity for researchers to "engage in a 2-year professional development and research experience to support the design and implementation of an engineering-focused Implementation Project at their home institutions, with the institution's support" [12]. This work typically involves preparing a submission for a grant-funded intervention at the PEER's home institution.

The data wing of Engineering PLUS (Continuous Improvement through Data, Evaluation, and Research, or CIDER) was established to support project leadership, researchers such as PEERs, and Hub member stakeholders. The CIDER team brings together a multidisciplinary effort to support the data-focused activities, research and evaluation of the Engineering PLUS Alliance. They are supporting the alliance's work by engaging their synergistic team of data scientists, researchers, and evaluators (internal and external) and creating a foundational platform that supports capacity building at the project, stEm Academy, the partnering societies, and Hubs. The CIDER team collectively has decades of experience in grant-funded education research.

To support these activities, the data wing of Engineering PLUS (Continuous Improvement through Data, Evaluation, and Research, or CIDER) has spent 3 years iteratively developing data visualization tools that allow engineering education researchers, practitioners, and stakeholders to easily interact with relevant data from several sources that could provide valuable context and support to their work, such as when securing grants or evaluating program performance. This has involved hosting a series of workshops to introduce stakeholders, researchers, and others to the data tool. Additionally, several internal meetings have been held and surveys deployed to Engineering PLUS stakeholders. These workshops, surveys, and meetings have served to assess user needs, gather feedback, and offer opportunities for collaboration with external partners to develop a distributable "framework" version of the tool that can be modified to meet an individual partner's needs.

III. Similar Efforts

There are several ongoing efforts to unify data within and across specific domains, either as static reports, data products, or visualization tools. Many of these efforts are "horizontal" in the sense that they seek to create broad regional or even national coverage of one particular domain of data (such as postsecondary data). Others are "vertical" in the sense that they intend to combine different domains of data, such as K–12 and postsecondary data. Some attempt to combine both of these approaches.

Federal agencies such as the National Center for Education Statistics (NCES) and the National Center for Science and

[1]Engineering Partnerships Launching Underrepresented Students

[2]National Science Foundation Eddie Bernice Johnson Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science

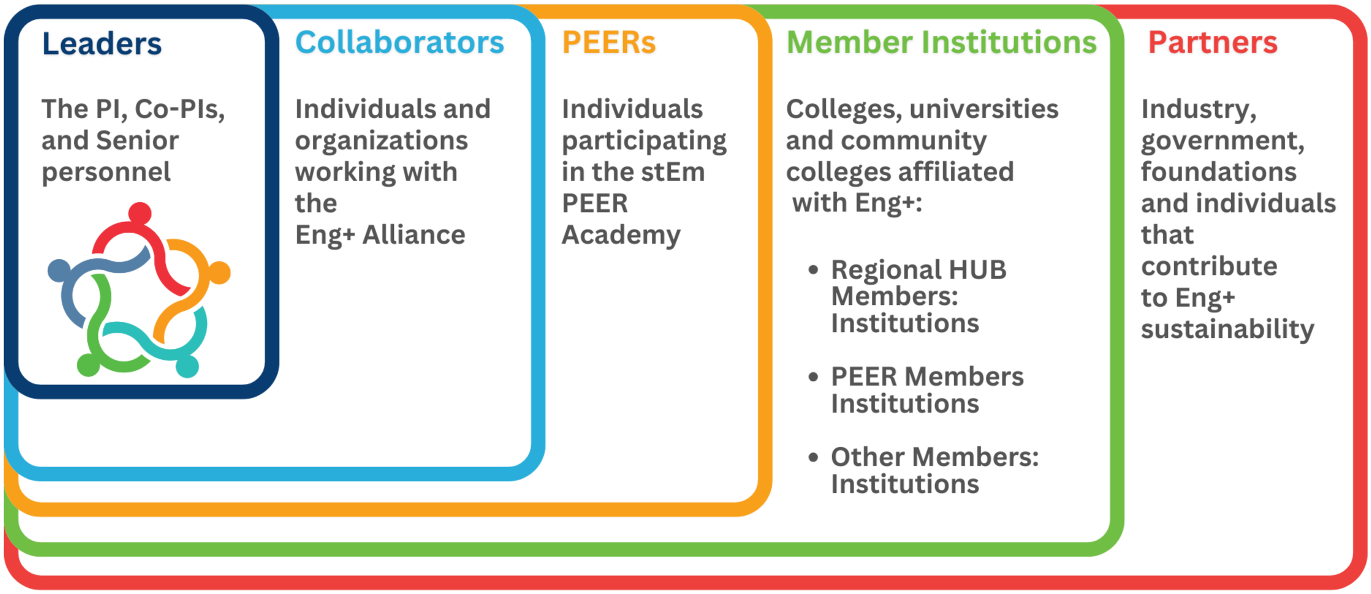

Fig. 2. Engineering PLUS membership

Engineering Statistics (NCSES) are pursuing efforts to unify educational data at the national level. The NCES provides access to many domain-specific surveys, such as their primary and postsecondary data surveys [3], [4], [13]. These surveys are typically disaggregated at the institutional level. The NCES and NCSES also provide table builder tools for a selection of their datasets; however these tools are generally limited to displaying information from one survey at a time. Organizations such as the National Student Clearinghouse and MIDFIELD provide even deeper insight across the postsecondary space by tracking individual students throughout their education [8], [9]. Other entities, such as the American Society for Engineering Education, provide yearly reports on the state of education.

State longitudinal data systems (SLDS) represent a method of vertical integration, typically combining data that track a student from entry into the preschool education system to exit from a postsecondary institution [16]. These data systems are limited to their home state however, potentially creating substantial difficulty when attempting to use data from several states to contextualize the impact of programs that cross state boundaries. Additionally, disaggregated data from these systems are frequently private with high barriers to access.

The NCSES is funding initiatives such as America's Datahub Consortium with the intent of solving some of the limitations of existing horizontal and vertical data systems. This includes broad unification of disparate data and providing lower barriers to obtaining traditionally difficult-to-access private data [14]. This work is still in its infancy, however.

While many of the aforementioned data can be integrated across domains with some amount of effort, one of their primary benefits is their coverage and longitudinal nature. Several organizations are also developing tools such as the NCES Table Builders or the NSF's By the Numbers reports. However, none of these larger, mature efforts both broadly unify data beyond education (e.g. combining local population data from the US Census with data from surveys of higher education) and achieve the level of granularity and interactivity desired by many researchers. Several novel tools developed by the CIDER team attempt to address this problem.

IV. The Engineering Education Ecosystem Landscape Framework

A. Initial Stakeholder Meeting and Needs Assessment

The development of tools to support engineering education researchers, leaders, and stakeholders required an iterative approach to identifying and addressing user needs. First, a discussion internal to Engineering PLUS was held about how the CIDER team could support these users more broadly. This meeting introduced collaborating researchers and the leadership team to the concepts of the tools that would be developed, including the Engineering Education Ecosystem Landscape Framework. Key takeaways from stakeholders at these meetings were:

- In addition to immediately relevant data such as postsecondary student and institution data, there is a need for data regarding employment opportunities such as engineering job openings and the location of various NSF-funded industry opportunities of interest to stakeholders.
- Any tool developed must be responsive to the data needs of individual Hubs and PEERs based on their activities, especially with regards to the specific regional context of each Hub/PEER institution.
- Stakeholders placed emphasis on using extant data rather than burdening Hubs, PEERs, or the CIDER team with additional data collection.

Additionally, an intake survey was distributed to Hub members to assess the practices and interventions currently taking

High-impact practice	Count of institutions
Financial support	26
STEM tutoring	26
STEM club or other STEM organization	25
Career counseling and awareness	24
STEM Professional guest speaker sessions	24
Academic advising	23
Undergraduate internships	23
Undergraduate research experiences	22
Early alert systems	20
Pre-college programs	20
Faculty development programs	19
Professional/academic skills workshops/seminars	19
Learning centers	18
Supplemental instruction/facilitated study groups	18
Targeted first-year programs	18
Pre-college summer bridge STEM programs	17
Diversity action plans	15
Near peer mentoring	15
Entrepreneurial programs (at any level)	14
Reforming curriculum and teaching practices	14
Collaborative learning / living environments	11
Institutional leadership engagement	11
Mentoring with peers of color	10
2-year to 4-year bridge programs	8
Positive identity development (for students)	8
Positive self-efficacy development (for students)	7
BIPOC mentoring programs	5
Transfer coaching	3
Graduate–PhD bridge programs	1

TABLE II
PRESENCE OF HIGH-IMPACT PRACTICES, BY INSTITUTION

place at their institutions. This would inform Hub members and the CIDER team about what (if any) interventions were generally favored by member institutions, and could also inform the CIDER team and other stakeholders as to what types of proven intervention proposals could be successful at different institutions. Additionally, this would inform the CIDER team as to which types of data would be the most broadly useful to engineering education researchers.

The Hub survey resulted in 31 responses from Hub members, each from a different institution of higher education. This included 15 faculty, 12 deans, and 7 department chairs. These represented 12 institutions with no more than 50 engineering students enrolled as of the time of the survey, 7 with between 51 and 300, and 8 with at least 300.

This survey demonstrated that institutions considered broad supports for their undergraduate and graduate students (Table II) as well as faculty preparedness and professional development. These supports also appeared to be broadly available, with many institutions reporting that these supports had no particular target population in mind (Table III). Finally, respondents typically reported that many of these practices had been in place for at least two years by the time of the survey.

Student and professional organization data was also demonstrated to be pertinent, with only 2 out of the 31 institutional respondents indicating that their institution did not participate with any major student alliances or professional organizations (e.g. the National Action Council on Minorities in Engineering, the Society of Women Engineers, etc.). The breadth of support offered reinforced the perceived need for

Target group	Percent of interventions
BIPOC	13.9%
Female	11.2%
Non-traditional students	4.4%
Students with disabilities	4.8%
Students with low socioeconomic status	9.2%
No specific population	46.6%
Other	10.0%

TABLE III
PERCENTAGE OF SUPPORTS OFFERED TO SPECIFIC GROUPS OF STUDENTS

broad longitudinal data, from student preparedness, to higher education equity, to workforce data.

B. Initial Tool Development

To meet these needs and facilitate discussion among stakeholders, the CIDER team began the development of the Engineering Education Ecosystem Landscape Framework [3]. This web-based interactive document was designed to create a "Landscape Report" that provides the data sources and means to describe the participation of people engaged in engineering pathways (from K–12 through employment), the capacity of the ecosystem to support engineering education, the access historically underrepresented populations have to that ecosystem, and to the experiences of the groups involved in engineering education. The Landscape Framework was structured to help users who may be unfamiliar with the data available to them to identify useful data sources in a self-guided manner.

Additionally, descriptive sections were added to stimulate discussion around how to contextualize engineering education data and the interventions that relied on these data. While the data sources included in the Landscape Framework are by no means an exhaustive survey of available engineering education workforce data, in the CIDER team's opinion it represents a collection of the most easily accessible, useful data available to STEM education researchers.

The Capacity, Access, Participation, and Experience (CAPE) framework [15] was used to organize this document. Originally developed to assess equity in computer science education, the CAPE framework outlines four components of the education pathway that can also be applied to equity in engineering education: capacity for, access to, participation in, and experience of education. Each level of this framework builds upon the prior level.

Each component of the CAPE framework was populated with example questions that could be asked of the data organized under itself. Some of these questions were provided by the CIDER team based on team member experience, while others were sourced from discussions with engineering education researchers. The rationale for organizing data in the Landscape Framework around CAPE was provided through similar discussions. It was found that the starting point for a proposed piece of work typically began with a locally observed problem or question, such as retention of a particular student

[3]This tool is available at https://www.sagefoxgroup.com/cider

Metadata	Example entry
Engineering Education/ Workforce Relevancy	How is funding distributed within institutions of higher education (e.g. student supports such as advising)?
Data Group	Education
Pathway Stage	4-Year Institution (Bachelor's)
Level of Disaggregation	Institution
Data Notes	Includes student financial data, population demographics, graduation rates, and other data.
Update Frequency	Annual (Select data Bi-Annually)
Source	https://nces.ed.gov/ipeds/

TABLE IV
LANDSCAPE DATA FRAMEWORK DATA SOURCE ORGANIZATION AND METADATA EXAMPLE

group (e.g. "How is funding distributed within institutions of higher education (e.g. student support such as advising)?"). This observed problem would then need to be verified and given context by relevant data in order to result in a successful proposal of work.

Each section of the CAPE framework was given a table of data sources listing metadata such as data location and relevancy to engineering pathway stage as seen in Table IV. This allowed users to procedurally narrow down a list of potentially useful data sources during grant-writing and inquiry processes. Users would first identify one or more CAPE domains based on the question(s) that they were asking, and then scan the appropriate table for relevant data sources. These tables draw from a live connection to a separate database to allow for low maintenance overhead while providing a means of updating the data source list.

The first year of Engineering PLUS was used to develop and populate this engineering education ecosystem framework, as well as collect feedback on its usefulness to engineering education researchers. Our focus was on the initial three states of the New England Hub (i.e. Massachusetts, Connecticut, and Rhode Island) as it bounded initial data collection and allowed us to explore the scope of available, accessible, and useful data. Feedback on the tool was solicited on an ad-hoc basis during stakeholder meetings and workshops. Feedback tended to be positive, with common feedback revolving around utilization of individual data sources within the tool.

V. The Engineering Ecosystem Data Tool

During development of the Data Landscape Framework, it was found that users required additional support once data sources were identified and accessed. Specifically, this involved the unification and visualization of the accessed data. Contextualizing BPE work frequently involves multiple disparate sources of data, but even single-source data manipulation tasks could be challenging for those with little time and/or experience with such work. This was especially true for those attempting to meet proposal deadlines, such as PEERs or other grant-funded researchers.

To this end, the CIDER team relied on previous experience and worked with users to identify the most commonly used/useful data from the Landscape Framework, brought these data together into a coherent database, and then created a visualization tool (example screens in Figures 4, 5, and 6) to allow users of a variety of skill levels to explore the data in a number of different ways. This involved unifying data from NCES IPEDS, NCES ELSi [4], the U.S. Census, and other CIDER-produced and maintained data (Figure 3) in order to capture the engineering education ecosystem end-to-end. The CIDER team also began transforming certain data in order to create approximations of frequently inaccessible data, such as retention metrics. Finally, the CIDER team utilized the Tableau visualization platform to create interactive tools based upon these data. This platform was chosen to ensure a low bar for entry into the tool, allowing for users with only a basic familiarity with drop-down menu interfaces. It is important to note that the Engineering Ecosystem Data Tool[4] developed to supplement, not replace, the earlier Engineering Education Ecosystem Landscape Framework.

VI. Deployment During Workshops & Feedback

After initial development, the CIDER team began iterative improvements to both the Engineering Education Ecosystem Landscape Framework and the Engineering Ecosystem Data Tool, with a heavier focus on the latter. Both of these tools were deployed to engineering education researchers during several demonstration and feedback workshops.

The Engineering Ecosystem Data Tool has seen use during these demonstration and feedback workshops with STEM PEERs and other EPLUS stakeholders in 2022, 2023, and 2024. The Engineering Education Ecosystem Landscape Framework saw use and feedback primarily in the first two workshops. These meetings have been attended by over 70 PEERs, Hub members, and other engineering education researchers representing more than 45 institutions of higher education. Attendees of each workshop were encouraged to follow along with a live demonstration of the tool, given the opportunity to participate in small breakout-room discussions with the creators of the Engineering Education Ecosystem Landscape Framework and the Engineering Ecosystem Data Tool, and asked questions/offered critiques.

Functionally, the tools were well-received. Most user interface feedback revolved around a desire for simplicity of data representation as well as strong emphasis on tools comparing various metrics from a user's institution to national or regional baselines. Several users even expressed interest in receiving the CIDER team's assistance in creating their own forks of the Engineering Ecosystem Data Tool so that they could integrate deeper functionality related to their own organizations' missions. Users also expressed keen interest in expansions of the Engineering Ecosystem Data Tool, including new visualizations for topics such as institutional comparisons (such as finding peer institutions of higher education), expanded enrollment information by demographic and discipline, and more. The authors found that once users had easy access

[4]This tool is available at https://www.sagefoxgroup.com/cider

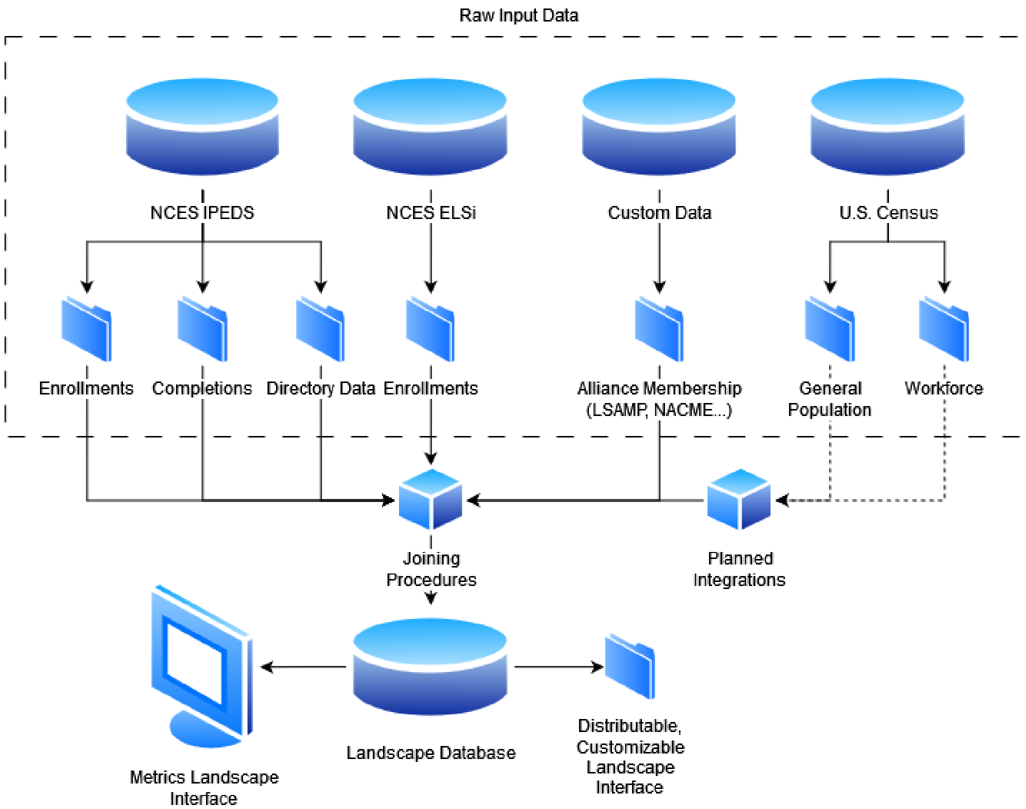

Fig. 3. Landscape database inputs and outputs

to their own institution's data, they developed a voracious appetite for this information.

One particular universally desired feature that has proven difficult to include was disaggregated retention data. The CIDER team found that it was frequently challenging to find these data disaggregated at a level that is useful to users. For example, publicly accessible resources such as the NCES provide general, institution-level retention data, but not the same data by factors such as discipline, race/ethnicity, and sex — factors frequently pertinent in grant-funded equity work. Sufficiently disaggregated data instead exist behind paywalls or institutional contracts, such as with MIDFIELD.

VII. Discussion & Future Work

The Engineering Education Ecosystem Landscape Framework and Engineering Ecosystem Data Tool have been well-received by the participating BPE community over the duration of its development. Combined, they represent a novel, valuable toolkit for researchers, stakeholders, and organizations engaged in improving engineering education. These tools address stakeholders' desire for easily accessible, broad data on engineering education. Initial deployment during trial meetings and the associated workshop series were met with enthusiasm and excitement, demonstrating the need for and great potential of similar tools that allow users to examine trends in engineering education so that they can better effect change in BPE.

Such tools are critical to advancing BPE. The ultimate goal of BPE is to facilitate change in engineering education – an interconnected system with great inertia and resistance to change that spans the entire lifetime of an engineer from early childhood to employment. It is thus vital to unify data from across the entire engineering education ecosystem so that engineering education researchers can properly evaluate the health of this system at institution, state, and national levels. It is also vital that these tools examine not just vertical slices, but the current and future trends in engineering education. Effecting real change in BPE means changing the course of existing trends in BPE.

Initial development on the project has concluded, but there is still much planned work to be done. Firstly, we wish to balance depth of insight and complexity with the needs of "data novice" users. To this end, we are planning to potentially split the tool into several independent-but-related data visualization tools. This will provide several "walled gardens" of data of a more limited scope that cater to different data manipulation and interpretation skill levels.

Secondly, we plan to integrate more data into the tool so that it can better provide insights into the entire engineering education ecosystem. While the tool currently makes K–12, postsecondary and alliance data available, data for PEER/Hub institutions and employment/student funding opportunities only exist in separate CIDER-developed demonstration tools at

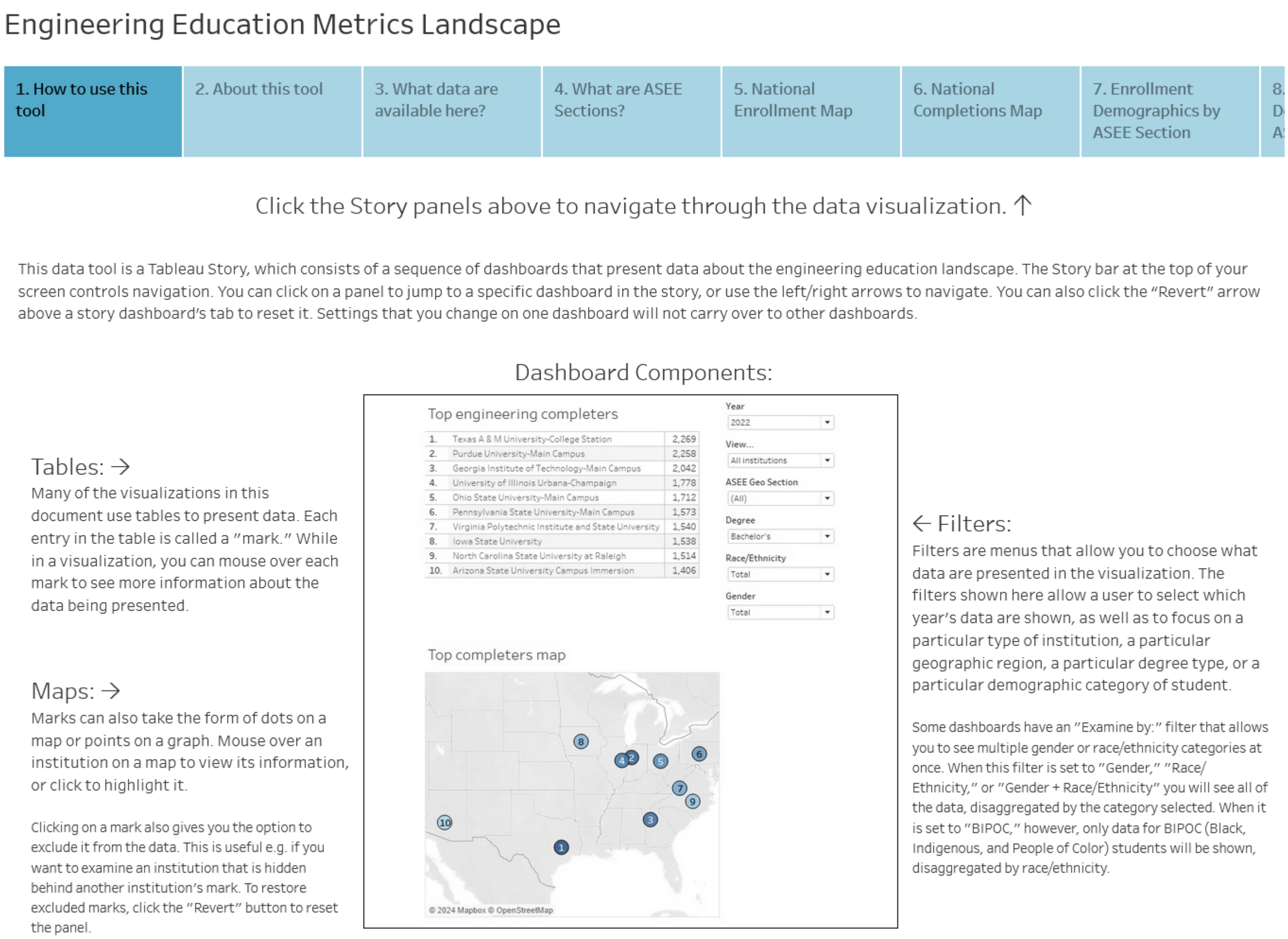

Fig. 4. Cover page of the Engineering Ecosystem Data Tool with general instructions.

this time. Other data, such as U.S. Census data, are integrated but not displayed at this time. Integration of these data into a single data toolset would improve usefulness and ease-of-access. Improved geospatial tagging is also planned. This would allow for better analyses to be performed, especially given engineering education IHEs' varying regional contexts. Substitute measures for frequently requested data that are difficult or impossible to freely obtain, such as retention data disaggregated by discipline, are also under consideration.

Another pressing concern is that of sustainability. Currently, the data tool is deployed in two places: one copy exists on Salesforce's Tableau Public platform, while another is privately maintained by a contractor working for Engineering PLUS. The former is vulnerable to the whims of Salesforce, and the latter is bound by the duration of the Engineering PLUS alliance's funding. While problems with the latter will be partially mitigated by transferring maintenance of the private platform to one of the member institutions of Engineering PLUS, we also plan to pursue sustainability through decentralization. Once the Engineering Ecosystem Data Tool has reached a stable release, the tool's source data and files will be available upon request. Several organizations and institutions of higher education have already expressed interest in obtaining the tool in this way.

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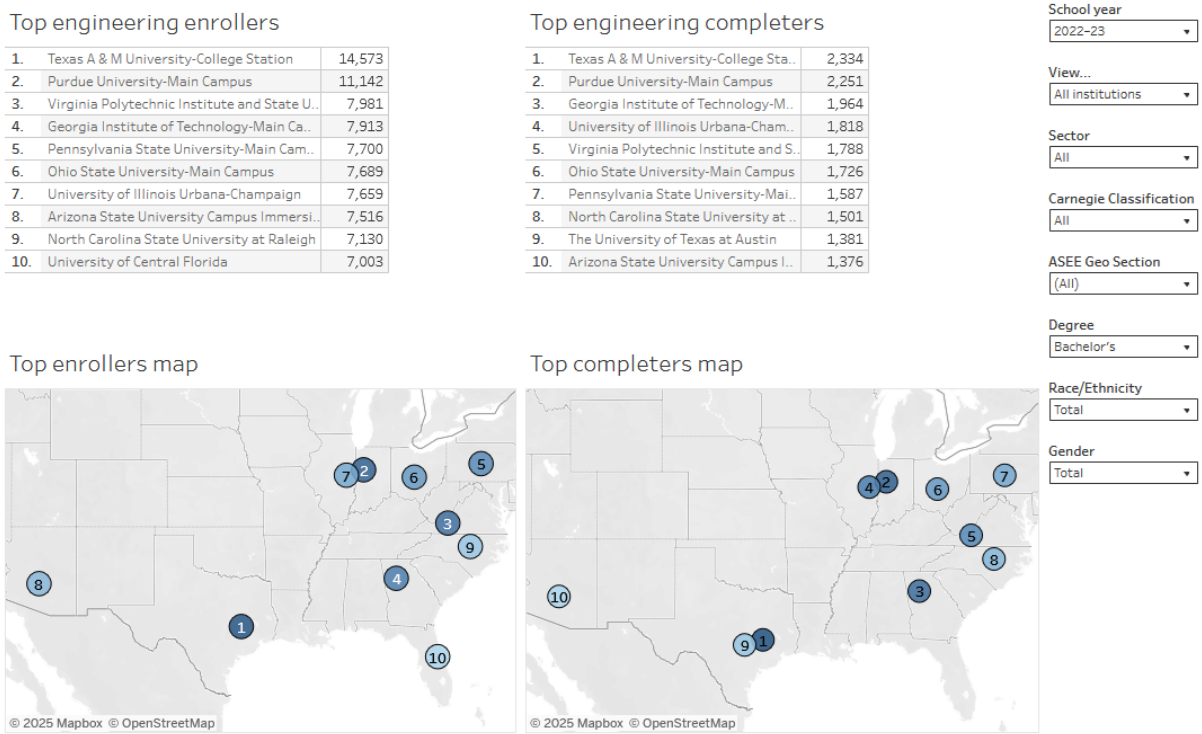

Fig. 5. Example usage of the Engineering Ecosystem Data Tool for viewing institutions that are the top 10 enrollers/completers. Can be viewed on a national or regional scale, among other factors.

Fig. 6. Example usage of the Engineering Ecosystem Data Tool for viewing the longitudinal completions data of multiple institutions at once.

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