Designing a data partnership to understand the engineering education system

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Structured abstract

BACKGROUND
Academic, industry, and government organizations in Australia and the United States of America have published reports in recent years expressing a need for a larger number of engineering graduates, more diverse engineering graduates, and for particular outcomes. Large-scale data analysis of the engineering education system can help understand what is happening to students without any significant threats to privacy.

PURPOSE
To propose a metadata structure that is general enough to be applicable to all universities yet specific enough to provide useful information about who enrols in engineering programmes and to what extent they are successful.

DESIGN/METHOD
This is desktop research based on reviews of national and state reports addressing engineering education needs in Australia and the United States and addressing the role of a student unit record database in measuring progress toward those needs. The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) was created in the United States of America in 2003 and now tracks the academic pathways of over one million degree-seeking undergraduate students, including over 200,000 engineering students.

The MIDFIELD metadata was designed to support the collection of data from multiple US institutions, and there are currently 11 institutional partners that contribute data to the project. Nevertheless, methodological developments have been necessary to study the diversity of institutions even in an 11-institution sample in the US. Even as MIDFIELD serves as a model for a data partnership in Australia, the additional diversity of the Australian institutions will help make the MIDFIELD metadata even more robust to institutional differences.

Results from studies of US data are provided to demonstrate what research questions can be answered using data that do not result in significant risks to students. For each example, in addition to findings from the US study, a description of how those findings can benefit various stakeholders is provided.

RESULTS
The AAEE conference is a high-priority venue to discuss plans for this data partnership with members of the engineering education community. Discussions remain open to metadata modifications as well as methodological developments. After the conference, new metadata structures will be proposed based on the collection and storage of institutional data in Australian institutions.

CONCLUSIONS
Based on the results of this work, partnerships within Australia will be cultivated to explore the engineering education system. Later comparisons between Australian data and US data will reveal how the same policies and approaches can yield different results in different cultural settings.

KEYWORDS
Longitudinal studies, Retention, Access, Success

Introduction

Recent reports in both Australia and the United States emphasize the importance of Science, Technology, Engineering, and Mathematics (STEM) fields in maintaining prosperity and global competitiveness in their countries (National Research Council, 2007; Office of the Chief Scientist, 2012). Reports in Australia point to extremely low engineering unemployment rates as a sign that the labour market in engineering is undersupplied and thus programs are needed to encourage more students to pursue degrees and careers related to engineering (Engineers Australia, 2012). While reports in the United States have made similar claims (National Science Board, 2012), some challenge those claims and more recent reports suggest that the need for engineers is diminishing, making this a less compelling argument for recruiting more students into engineering programs (Engineers Australia, 2013).

Regardless of the current dynamics of supply and demand of engineering graduates, there is general agreement that understanding the dynamics of the engineering education system is important to the economic wellbeing of both Australia and the United States. A knowledge of the correlates and predictors of access, performance, and completion has potential for improving the experience of students, the effectiveness of academic staff, the fiscal viability of engineering programs, and the satisfaction of employers.

In this paper, we provide an overview of the Multiple-Institution Database for Investigating Engineering Longitudinal Development, a database that was created with data from institutions in the United States in 2004 and that has led to findings of importance to researchers, funding agencies, administrators, academic staff, and students.

Studies of retention and student success

Typical of the literature on engineering education in the United States, the literature on engineering education in Australia has many studies that are focused pedagogical interventions that inform teaching practice, but are limited in their ability to explain the dynamics of the larger engineering education system. Some studies of engineering student retention are constructed from ill-suited datasets that permit only cross-sectional analyses that are subject to significant misinterpretation. Longitudinal studies are available at multiple levels of the engineering education system, but each faces its own challenges.

The Longitudinal Surveys of Australian Youth (LSAY) are designed to document student transitions and pathways (ACER, 2013), yet the most comprehensive study of STEM students using LSAY data fails to disaggregate the various STEM discipline and focuses more on factors affecting enrolment in post-school STEM programs rather than the dynamics of education in post-school programs, where higher education institutions have more control (Lim, Ronnie & Nhi, 2008).

A longitudinal study of engineering education graduates is based on a rich data set, but due to limited resources, the sample size is small by the standards of quantitative studies—the findings are not generalized even to a larger sample from the single institution involved in the study (Tilli & Trevelyan, 2008).

An excellent summary of the literature on engineering retention and attrition in Australian institutions is provided by Godfrey, Aubrey, and King (2010). This work includes a longitudinal study of student pathways supplemented by survey data and some elements of the study used whole population data. As the authors note, however, this was a single-institution study, limiting the applicability of the findings.

To understand the dynamics of the Australian engineering education system, a multi-institution, longitudinal, unit-record dataset is needed. Such a dataset will improve the accuracy of metrics that are already used and provide the ability to measure important outcomes that cannot be determined with data available currently.

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD)

In 1996, a longitudinal database was created containing student records from each of the universities participating in the Southeastern University and College Coalition for Engineering Education (SUCCEED), a Coalition of engineering colleges in the United States sponsored by that country's National Science Foundation. This database was designed in response to the need for greater accountability in coalition activities and included records of students matriculating 1987 and later to provide baseline data for cohorts of students unaffected by Coalition activity.

MIDFIELD was created in 2004 as a successor to that earlier database to include more current data and additional data elements. While the original SUCCEED longitudinal database contained only the nine SUCCEED partner institutions, MIDFIELD is dynamic and has grown to include additional institutions and includes data updates from partner institutions. Data from all partner universities are placed in a common format, so MIDFIELD can be used for cross-institutional studies. A data dictionary and a sample Memorandum of Understanding for MIDFIELD partners are published online (Long, 2012).

MIDFIELD comprises whole population data for undergraduate, degree-seeking students. This results in a dataset that comprises more than one million unique students at 12 institutions. Of those, more than 200,000 were ever enrolled in engineering, and more than 85,000 graduated with a degree in engineering. MIDFIELD institutions award more than 10% of all US engineering bachelor's degrees annually. The data structure of MIDFIELD is a blend of the data that institutions collect, which is likely to have a significant amount of congruence with Australian data collection practices, since the mission of higher education institutions in the US and Australia are similar. MIDFIELD is large enough to support disaggregation across multiple important variables and contains longitudinal information on each student to avoid the limitations inherent in cross-sectional data or in the construction of synthetic cohorts.

A considerable amount of research has been conducted using MIDFIELD, resulting in 12 publications in journals and more than 50 in conference proceedings, 12 other conference presentations, a book chapter (Ohland, Orr, Lundy-Wagner, Veenstra, & Long, 2012), and a book (Camacho & Lord, 2013). The quality of research using MIDFIELD was recognized with the best paper award in the Journal of Engineering Education in 2008 and 2011 and the best paper in the IEEE Transactions on Education in 2011 (Ohland et al., 2008; Ohland et al., 2011; Lord, Layton, & Ohland, 2011). Ohland and various research colleagues have also received best paper awards at two national conferences (Zhang, Thorndyke, Carter, Anderson, & Ohland, 2003; Ohland & Collins, 2003). MIDFIELD results have been disseminated through participation in panels (Batchman et al., 2005); Long & Ohland, 2011; Brawner et al., 2011), an invited workshop at an NSF grantees meeting (Ohland, 2009), four keynote addresses (Ohland, 2005; Lasser & Ohland, 2003; Ohland, 2012; Lord, 2010), twelve invited talks, and various media outlets (Basken, 2009). MIDFIELD researchers have been particularly successful in studying the impact of race/ethnicity, socioeconomic status, and gender on success in engineering education and were recognized with the Betty Vetter Award for Research by the Women in Engineering Proactive Network for exceptional research committed to understanding the intersectionality of race and gender.

Input from Stakeholders on Privacy, Confidentiality, Costs, and Benefits

The National Center for Educational Statistics (NCES), a division of the United States Department of Education, studied the feasibility of expanding the Integrated Postsecondary Education Data System (IPEDS) to include student unit-record data in 2005. The stakeholders that NCES consulted in that study opposed the extension of IPEDS primarily because of concerns for privacy and confidentiality and an unwillingness to assume the cost burden that would result (Cunningham & Mlam, 2005). Privacy, confidentiality, and cost

remain relevant, and developing a national database requires addressing those issues. Two of the authors conducted interviews and focus groups with higher education administrators and data managers to gather input on these important issues as well as data management, coordination, and methodological issues.

Student Privacy

The issue of privacy is particularly concerned with a student's right to withhold their participation. The large-scale implementation of such a system and its retrospective nature (in particular the inclusion of students who can no longer be contacted) not only precludes obtaining informed consent to participate in the database, but also makes informing all the participants impractical. While the government itself can require such reporting, other concerns arise if such a database is operated by the government. During interviews and focus groups in the past year, various participants expressed concern that government control would make participation an unfunded mandate, which would make participation a political issue and would disproportionately penalize institutions that have fewer resources to devote to data management—drawing what resources they have for institutional research to focus more energy on providing data to an external agency rather than directing their efforts at institutional improvement. Further, government control would not necessarily extend data comprehensive data access to the institutions themselves.

In the United States, an exception in the Family Educational Rights and Privacy Act (20 U.S.C. §1232g, (B)(1)(f)) allows institutions to provide student data to "organizations conducting studies for, or on behalf of, educational agencies or institutions for the purpose of … improving instruction, if such studies are conducted in such a manner as will not permit the personal identification of students and their parents by persons other than representatives of such organizations and such information will be destroyed when no longer needed for the purpose for which it is conducted." In developing a national longitudinal student unit-record database in Australia, it will be critical to identify related legal restrictions and how their conditions may be satisfied.

Based on current MIDFIELD practices, interview and focus group participants were confident that student privacy could be protected.

Student Confidentiality

From a research perspective, tracking students with a federally issued identification number is of significant value—the Social Security Number (SSN) in the United States would serve this purpose. In Australia, the Commonwealth Higher Education Student Support Number (CHESSN) provides a useful identifier that does not connect to tax and medical records. Such a common federal identifier could potentially be used to connect otherwise disparate data sources—academic records, financial data, employment data, education records from multiple institutions, and more. Nevertheless, the storage and research use of such an all-purpose identification number poses a very great risk. Fortunately, much can be learned using a longitudinal student unit-record database with an independent (and otherwise meaningless) identifier. Further, the internal MIDFIELD identifier is unrelated to any local campus identification number. As a result, the de-identified data in MIDFIELD pose little threat to confidentiality. To identify MIDFIELD data as belonging to an actual individual, it would be necessary to know a great deal about that individual's record. Original institutional data (before de-identification and conversion to the MIDFIELD common format) resides on a computer that is not networked.

Student confidentiality is also protected by reporting results only when minimum cell sizes are met. This expectation has always been honoured by MIDFIELD researchers and is a data use requirement for all who have access to MIDFIELD data. For basic issues of confidentiality, minimum cell sizes as low as five are used in practice. In research using MIDFIELD, our practice is to require a minimum cell size of 10 for any kind of public reporting. A minimum cell size of 100 is generally required for the discussion of population trends. In addition to these adopted practices, certain statistical procedures have

recommended minimum cell sizes—MANOVA, for example, 20 is the recommended minimum cell size (Hair, Black, Babin, Anderson & Tatham, 2006). Researchers are also expected to avoid reporting extreme events that could compromise the confidentiality of entire subpopulations.

Institutional Confidentiality

In the operation of MIDFIELD, the confidentiality of institutions has been protected as well. While results from a specific institution may be shown, MIDFIELD findings are not linked to specific institutions. Findings have sometimes been linked to sub populations or policies, but only where those did not betray the confidentiality of students or institutions. Conclusions have shown student trends and explored institutional variability without compromising these three important principles:

1. Institutional data are provided to the MIDFIELD project on the condition that researchers protect the identity of the partner institutions and each institution's students.
2. Increasingly specific institutional descriptions discourage readers from considering MIDFIELD research to be generalizable, in spite of other significant evidence that there is much that is common among engineering programs and their interaction with students.
3. While MIDFIELD includes data for very large numbers of students, relatively few institutions are represented, so institutional variation must be treated using a case study approach. Conscientious institution-level analysis would require a large number of diverse institutions.

While this plan would increase the number and diversity of MIDFIELD participants, interview and focus group participants were adamant about protecting institutional partners from harm. Institutional representatives were concerned about a variety of negative outcomes:

- Judging an institution by metrics that do not measure what the institution values.
- Comparing an institution to others using a metric that intends to measure what the institution values, but where the metric is defined in a way that favors other institutions.
- Releasing information that might provide an advantage to institutions competing for funding. This concern was most acute among schools competing for funding within a state system within the United States.
- Focusing on outcomes without regard for the initial preparation of the students.

Recognising the importance of institutional identity to the interpretation of research findings, institutional representatives generally accepted that the institutional identity could be revealed to researchers, but institutions retained the expectation of confidentiality in published findings.

Institutional costs

The initial costs of developing a national student unit-record system are of greater concern than the maintenance costs. From the perspective of the institutions providing data, this imposes two conditions. Generally, institutions expected external support to extract archival data. The cost of this varies considerably, particularly in that many institutions have implemented new data systems since the early 1990's. In some cases, legacy data before the adoption of a new data system are simply unavailable. Without external support, only institutions that have a long and consistent history of data management will be able to provide data, which would result in a significantly biased institutional sample.

To avoid burdening the institution, MIDFIELD's central team has always done the work to convert institutional datasets to the MIDFIELD common format. The personnel time required for converting an institution's data is related to the complexity of the data structure and the number of times the institution's data structure has changed in the period of interest.

Institutional benefit

An advantage of this work is that engineering is supportive of an assessment culture due to its outcomes-based accreditation requirements—both in the United States and in Australia. To the extent that a nationwide unit-record system could provide data that would be useful for self-assessment and accreditation, the system will have intrinsic value to engineering degree programs. Although this value is secondary to the direct benefit to the institution of the improvements that might be made, improvements in the ability to document outcomes for accreditation is sufficient motivation for engineering programs and the institutions that value them to commit financial, technical, and intellectual resources to help design, test, and improve a national student unit-record system.

Coordination issues

The concern was raised that the data needed for this system is held by various entities that may include the offices of the academic registrar, admissions, and institutional research. During interviews and focus groups, institutional representatives indicated that the adoption of comprehensive student record systems has helped unify institutional data. Further, there has been considerable interest in the past decade in integrating data systems. While this is still a concern, particularly regarding historical data, the institutions were generally not concerned by the issue of data coordination.

Proposed metrics

Expanding access to MIDFIELD to a larger research community will accelerate the development of new metrics that can be peer reviewed, including metrics that require a dataset like MIDFIELD. MIDFIELD researchers have already proposed some such metrics:

- A “percent of degree program completed” metric would classify student progression consistently at any point in time, regardless of mode of entry, and regardless of speed of completion. This will make it possible to compare full-time and part-time students, first-time-in-college and transfer students, and students who switch majors. When students switch majors, this metric would need to be recalculated on the basis of the new major. The challenge of this metric is the time it takes to map all the courses in all the curricula in all the years for all the majors at all the institutions in the dataset. This process is nearly complete for all engineering majors for the time period of the database at all current MIDFIELD partners, but it is unlikely to be scalable to a nationwide dataset.
- The “stickiness” of a major is how likely students are to “stick” to that major once they choose it—regardless of what other majors they have had, what other institutions they have attended, or how long they have been in college when they first enroll in that major. The stickiness of a major is the number of students who graduate in that major divided by the number of students who have ever been enrolled. This metric requires a single assumption: that selecting a major indicates intent to graduate in that major (Ohland, Orr, Long, Layton & Lord, 2012).
- Peer Economic Status (PES) is a measure of the average economic status of a student’s secondary school, and is a significant predictor of college persistence (Ohland, Orr, Lundy-Wagner, Veenstra & Long, 2012). The PES variable uses data from the National School Lunch Program in the United States and is coded so that a higher value corresponds to a better peer economic status, or PES = 100 – (percent of students in HS eligible for free lunch), which is a number between 0-100.

The design specifications for providing access to a national student unit-record data system

Based on input from interviews and focus groups with engineering administrators, engineering education researchers, academic registrars, institutional research staff, and data archivists, a unit-record database should be designed with four principles in mind:

Data should be accessible to a broader community of researchers. Institutional representatives interviewed recognized the benefits of allowing the research community to have access to a national student unit-record data system. In addition to accelerating the work of current engineering education researchers, access to MIDFIELD will be used by demographers, sociologists, statisticians, and others to study questions of interest to engineering education and other disciplines.

Partner institutions must not be affected negatively by published research results. To protect the partner institutions, names of MIDFIELD partners are never associated with specific statistics or calculations. Tables and figures mask the identities of institutions in published data. Institution names are used only when data is aggregated across institutions, and when it is not possible to deduce information about a single institution.

Partner institutions should have special access to conduct peer comparisons. Institutional representatives wanted to use MIDFIELD data conduct peer comparisons, yet they were unwilling to allow other institutions to have that level of access to their data without some indication of shared risk and trust. Findings from such studies should not have the opportunity to have a negative effect on institutions. Such peer comparisons can be directed by any investigator who holds a full time appointment at a MIDFIELD partner institution, but the results from such comparisons must be used solely for institutional analysis.

All institutions should have equal access to benefit from the MIDFIELD partnership. To ensure that MIDFIELD does not become a resource that further privileges schools that have the resources to participate, but that is out of reach of institutions with less resources devoted to institutional research efforts, external funding must support data extraction. Further, while published research that generates institutional findings must mask institutional identity, institutions must privately be informed of their own identity in published studies so that less-resourced institutions will benefit from research conducted elsewhere.

The Metadata Life Cycle

Historically, MIDFIELD metadata has been stored at the local level in a codebook or on the MIDFIELD webpage in HTML (Long, 2012). The life cycle of the data was limited: a study was designed, administered, and then archived on a local, secure computer. To expand the availability and use of MIDFIELD data, we will follow the Metadata Life Cycle and metadata standards as defined by version 3.1 of the Data Documentation Initiative (DDI) (2009).

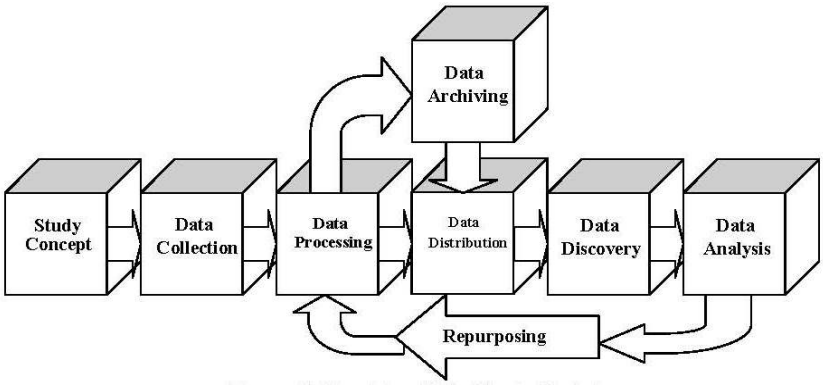

Figure 1. The Metadata Life Cycle

The Combined Life Cycle Model incorporates either direct dissemination to users or dissemination through data archives and recognizes that data can be reprocessed at later points in its life cycle, creating an iterative process. This means that the metadata life cycle is no longer linear but has become circular. This new model views the repurposing of data as being a secondary use of the data from a study. It is not the creation of multiple products from the same data collection such as a confidential data file, a public use file, and an aggregate data file. Using the DDI standards will ensure compatibility with ICPSR data archiving standards.

Study Concept - This new model will open the dataset to a myriad of research questions asked by researchers from a broad range of academic disciplines (e.g social sciences, STEM (Science, Technology, Engineering & Mathematics), business, economics, higher education). No longer will access to MIDFIELD be granted to only a few researcher studying engineering students.

Data Collection – MIDFIELD currently collects a standard set of student record data from member institutions. Data is transmitted via compressed, password protected files, either on physical device or electronically. Memoranda of Understanding strictly govern the use of data. MIDFIELD protects student and institution confidentiality. Institutional data is stored on a password protected, non-networked computer and is only available to a core team of MIDFIELD staff. As part of some MIDFIELD studies, qualitative data is collected in the form of surveys, recorded interviews and written observations. This qualitative data is stored and processed on password protected computers at the location of the study's Principle Investigator. Currently, there is not a central repository for qualitative data collected as part of MIDFIELD studies.

Data Processing – Data collected from member institutions is processed to ensure a common set of variable values. Institution files are merged into larger files – still maintaining a four file structure.

Data Archiving and Distribution – MIDFIELD data collected in the United States and associated metadata will be archived and distributed using the *Interuniversity Consortium for Political and Social Research (ICPSR)*. ICPSR (2013) provides leadership and training in data access, curation, and methods of analysis for a diverse and expanding social science research community. For national student unit-record data collected in Australia, one logical archive location would be the Australian Data Archive (ANU, 2013), which provides a national service for the collection and preservation of digital research data and to make these data available for secondary analysis by academic researchers and other users.

Data Discovery – One of the biggest challenges for researchers is finding out what data exists and how it can be accessed. ICPSR and ANU allow researchers to search available data files by topic, series, geography or investigator.

Data Analysis – With greater access to MIDFIELD researchers will be able to transform and model the data with the goal of highlighting useful information, suggesting conclusions, and supporting decision making.

Repurposing – Data files from analysis will be processed and the Life Cycle begins again.

Conclusions

A national student unit-record data set will be of significant benefit to researchers and institutional analysts, and the MIDFIELD partnership in the United States can serve as a model for such a data-sharing partnership.

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