Developing Data Analytics Skills for Complex Thinking Among Tomorrow's Global Engineering Leaders

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Abstract

The global engineering workforce needs to have the ability to analyze 'big' data sets critically to understand how and when to apply data in various settings and also understand how data can be interpreted to reveal a deeper contextual understanding about risks involved from multiple perspectives. In order to be able to provide aspiring engineering professionals with the complex skills necessary to use a variety of data sets, undergraduates require exposure to fundamental skills, challenging problems based in real world settings, and exposure to undergraduates with different disciplinary perspectives. This paper will provide an overview of a university-wide effort to facilitate the development of the fundamental data analytics skills through transdisciplinary workplace relevant learning opportunities that bring engineering students together with the sciences, social sciences, humanities, and arts. Discussion will focus on the transdisciplinary faculty design effort and how industry professionals were involved in the construction, implementation, and support of the effort. Discussion will focus on the curriculum that is offered through a Data and Decisions Minor as well as the opportunity to earn a Digital Tech Credential that is co-approved by a consortium of employers and institutions in the Capital Collaborative of Leaders in Academia and Business (CoLAB). The information presented in this paper provides an opportunity for universities and industry professionals to consider creative partnerships that can better prepare future leaders of the engineering workforce. Engineering educators and future employers can use the findings presented in this paper to consider how to implement similar approaches at other institutions.

Keywords
Data analytics, complex problem solving, transdisciplinary

1. Introduction
The global engineering workforce needs to have the ability to analyze 'big' data sets critically to understand how and when to apply data in various settings and also understand how data can be interpreted to reveal a deeper contextual understanding about risks involved from multiple perspectives. Recent studies have cited the need to have a workforce that has strong technical data analytics skills coupled with the ability to communicate findings. Technical knowledge combined with skills such as effective written and oral communication allows individuals to work across an organization to make recommendations based on results derived from analyses (Canada's Big Data Consortium 2022). International reports underscore the need to have a workforce that is equipped with problem solving skills that allow them to think critically and analytically to address challenges (World Economic Forum 2020). These reports are coupled with trends that indicate the workforce will need to have higher order cognitive skills such as critical thinking, decision making, and complex information processing in order to be positioned to productively contribute to technical

problems that have societal impact. These trends are especially relevant to areas such as manufacturing and other engineering related industries (McKinsey and Company 2018). Moreover, large scale market analyses suggest that in order for sustained economic viability engineers are one group that can immediately address the labor shortage. Engineers typically possess knowledge and exposure to computational methods and with modest additional training in data analytics and the use of data for problem solving they could become a group of qualified individuals for data related positions (Burning Glass 2017; McAfee and Brynjolfsson 2012; Manyika et al. 2011; NITRD, NCO 2016).

In order to be able to provide aspiring engineering professionals with the complex skills necessary to use a variety of data sets, undergraduates require exposure to fundamental skills, challenging problems based in real world settings, and exposure to undergraduates with different disciplinary perspectives (Barber 2020; National Academies of Sciences, Engineering, and Medicine 2018). Literature also suggests that in order to prepare students to grapple with large data sets and use data effectively they need exposure to a variety of disciplinary contexts (Forrester and Marshall 2021). These types of curricular experiences, often referred to as an integrative learning approach, have students continue to master a disciplinary field while they also gain a broad understanding of other disciplinary methods, approaches, and concepts (Kauffman et al.2003; Miller 2005). Integrated learning experiences allow students to apply content knowledge from their discipline or major, learn from other disciplinary fields, and engage in deep learning that does not prioritize one discipline or field over another. Integrated learning experiences are typically hands-on, problem-based learning experiences that require collaboration and team-based interaction among students (National Academies of Sciences, Engineering, and Medicine 2018). The hands-on features allow direct engagement and learning to take place from real-life scenarios (Kolb 1984). Many universities are considering how to use transdisciplinary approaches to advance integrative learning and associated complex thinking skills (Amelink and Nicewonger, in review; Baptista and Vilsmaier 2021; Crow and Dabars 2015).

2. Institutional Context

Virginia Tech has set forth goals to offer a comprehensive education that will allow students, regardless of major, to lead in developing responses to technological challenges confronting society. In response to calls for university structures that prepare students for a global economy (Baptista and Vilsmaier 2021; Crow and Dabars 2015), a main component of this university wide goal is to offer an undergraduate experience that allows students to address the technological challenges with an understanding of how they impact the human condition. As an outgrowth of this effort the university identified nine transdisciplinary thematic areas of emphasis where the university already had substantial faculty engagement in teaching and discovery. The nine transdisciplinary areas also allowed for cross-college participation of students and faculty and were relevant to society, industry, and funding agencies. Embedded in this effort was the desire to produce engineering students that have important data skills coupled with the ability to use data to make decisions. One of the thematic areas was Data and Decisions. The other eight thematic areas included: Adaptive Brain and Behavior, Creativity + Innovation, Economical and Sustainable Materials, Equity and Social Disparity in the Human Condition, Global Systems Science, Integrated Security, Intelligent Infrastructure for Human Centered Communities, and Policy. Each of the nine areas has a Transdisciplinary Community structure supporting it which includes a faculty led stakeholder committee that is provided with institutional support, including both seed funding and a significant number of new transdisciplinary faculty positions. Faculty participants are recruited from STEM disciplines as well as the humanities and social sciences.

Each of the Transdisciplinary Communities of faculty, including Data and Decisions, were charged by university leadership with designing transdisciplinary learning opportunities. In several cases the Transdisciplinary Communities developed minors that are available to all students. The minors include a transdisciplinary introductory course, a series of elective courses that provide students with disciplinary depth in key areas associated with the transdisciplinary thematic area, and a transdisciplinary capstone course. Hands-on learning opportunities that allow students to apply critical thinking skills to real world problem sets is a cornerstone of the introductory course and capstone course.

At the time of this writing, 7 of the 9 Transdisciplinary Communities have developed 6 minors and one graduate certificate available to students in all disciplines. Table 1 provides an overview of these Transdisciplinary Communities, the minors and certificates they have developed, and how the curriculum was designed to offer integrated learning experiences for STEM and non-STEM students.

Table 1. Summary of Curricular Experiences Designed to Advance Complex Thinking Skills

Transdisciplinary Community	**Minor/Graduate Certificate**	**Curriculum Summary of STEM and Non-STEM Engagement**
Adaptive Brain and Behavior	Adaptive Brain and Behavior Minor	An interdisciplinary program where the natural sciences, social sciences, and biomedical engineering converge to provide a deeper understanding of interaction between the brain, behavior, and environments. Students explore the interplay between neurobiological systems and psychological and social factors, and the role of neuroplasticity. The minor gives students a comprehensive scientific framework for analyzing human behavior and the factors that promote optimal development.
Creativity + Innovation	Innovation Minor	Opportunities to practice innovative problem-solving skills, as well as elective credits for students to pursue their personal interests; helps students expand their entrepreneurial ideas through customer discovery and business model activities.
Data and Decisions	Data and Decisions Minor	Develop skills to think critically and use data responsibly to formulate judgements beyond their personal inferences; students will be able to consume and use data responsibly, ethically, collaboratively, effectively, and efficiently.
Economical and Sustainable Materials	Materials and Society Minor	A broad science-based overview of chemistry and materials through discussion of everyday products we use and discard.
Integrated Security	Integrated Security Minor	Teaches students about global security from a political, business, and technological standpoint; uses a highly innovative Integrated Security Research and Education Center to teach through simulated learning.
Intelligent Infrastructure and Human Centered Communities	Technology, Humans, and Environment Minor	Equips students with the knowledge and skills needed to simultaneously understand the capabilities and risks presented by technologies and explore the ways those technologies can advance more livable and sustainable communities.
Policy	Science, Technology, & Engineering in Policy Graduate Certificate	Enhances the capacities of science, technology, engineering, mathematics, and health care (STEM-H) students, practitioners, and scholars to be effective participants and collaborators in policy processes. The program develops participants' abilities to engage with complex public problems, recognizing that they are social and technical in nature.

3. Data and Decisions Minor and Certificate

The Data and Decisions Minor is designed to provide engineers and others with the skills needed to use data to assist in making decisions. The minor provides exposure to methods of gathering data, how data can serve as a resource for presenting objective information, and how data can help evaluate risk or the lack thereof from multiple perspectives. Additionally, the minor helps develop skills in critical thinking and challenges students to use data to formulate judgements beyond their personal experiences and preferences. The coursework emphasizes how to use data ethically and responsibly to make decisions. In total, the Data and Decisions minor involves 18 credit hours and includes 3 hours of introductory restricted electives, 6 hours of core requirements, 6 hours of elective courses selected from a list, and 3 hours of a Data and Decisions Capstone. The electives include topics such as: environmental informatics; introduction to remote sensing; social research methods; digital history; data governance; and privacy and ethics. The core courses are designed to be of interest to a variety of students and backgrounds. For example, the core course Computational Modeling and Data Analytics "Data Matter" course develops fundamental analytical and programming skills that allow students to conduct a comprehensive analysis, including specifying research questions, selecting/collecting data ethically and responsibly, processing and summarizing datasets, and stating findings, while considering all assumptions made.

The course teaches one or two technical approaches for both collecting and summarizing data for at least three different data types (i.e., quantitative data, text data, and image data) and addresses analytic needs in the hard sciences, social sciences, and engineering sciences. The Business Information Technology/Management Analytics in Action capstone course for the Data and Decisions Minor presents students with problem-solving frameworks and analytic techniques for solving messy, unstructured, high-impact, real-world organizational/societal problems within an interdisciplinary, intercultural, experiential learning context. The course covers definition of problem scope, objectives, need for change, ethical concerns, and diversity and inclusion issues; identification of stakeholders and their values; evaluation of decision tradeoffs; problem decomposition and hypothesis formulation; project planning and administration; data versus user requirements, ethical and inclusive decision making, data collection, preparation, and analysis; team roles and management; professional communication of insights, policy and action recommendations. An overview of the Data and Decisions curriculum is provided in Figure 1.

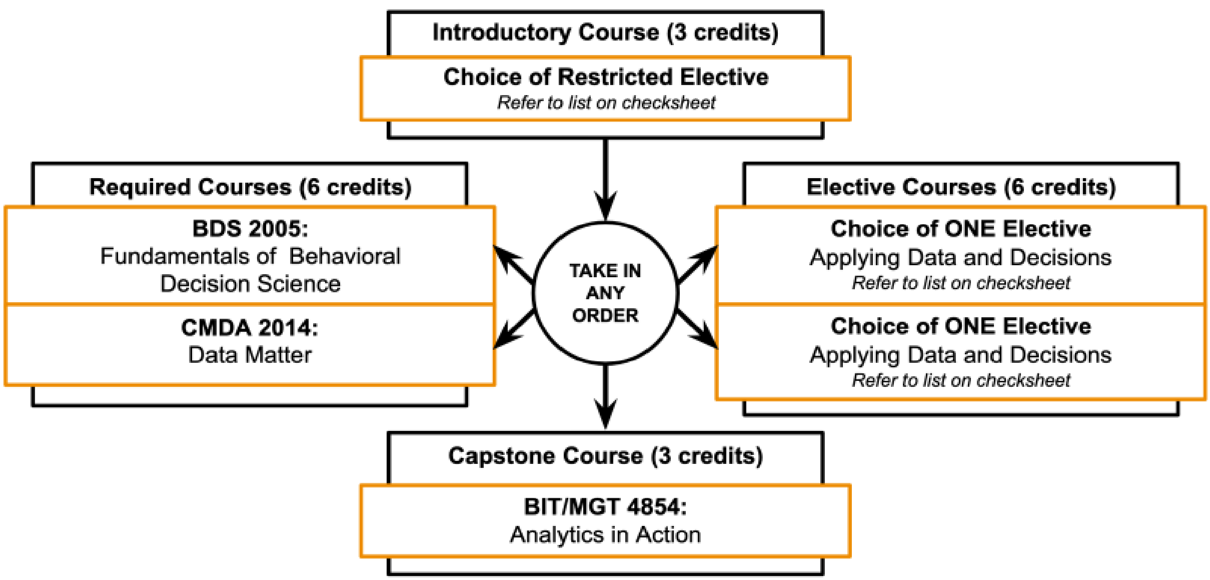

Figure 1. Overview of Data and Decisions Curriculum

In addition to attaining a minor, students that complete the Data and Decisions Minor coursework and also complete an additional elective (i.e., Business Information Technology *Data Governance, Privacy, and Ethics*) can earn a Capital CoLAB Digital Generalist Credential, the Capital CoLAB Digital Generalist Credential. The CoLAB is a partnership of business and academic institutions that are working collaboratively to develop talent pipelines that address workforce needs related to data analytics skills. The certificate is designed to signal to hiring agencies that graduates have the immediate skills necessary for job roles that require an understanding of data analysis and visualization as well as data security. The CoLAB was facilitated by the Greater Washington Partnership. The Partnership is an organization of industries in the larger metropolitan region covering Washington D.C., Baltimore, Maryland and Richmond, Virginia. The Partnership is working to develop inclusive economies that support continued economic growth and have highlighted the need to develop talent pathways that address needs in data analytics skills. Students that attain the Capital CoLAB Digital Generalist Credential through completion of the Data and Decisions Minor are of great interest to industries in the Partnership that are recruiting for jobs that require data skills.

4. Conclusion

To date, the curricular experiences that are part of the Data and Decisions effort have provided unique opportunities for currently enrolled engineering students as well as students more generally to develop data analytic skills as well as decision making skills. In addition, the curriculum advances communication skills and team-based collaboration skills which are highly sought after in the workforce. Students demonstrate their mastery of these important skills with the attainment of a minor and potentially with an additional workforce relevant certificate. Future efforts plan to examine more closely the specific learning outcomes of the students and the long-term outcomes as students matriculate into full-time jobs.

In conclusion, the efforts at Virginia Tech to facilitate interaction between faculty from different and departments to design curricular offerings in key thematic areas has produced a series of learning experiences that are unique and important for the future workforce. The holistic experience that includes multi-disciplinary team-based learning around real world data challenges is developing future engineers that will have the skills necessary to analyze, use, and evaluate data more effectively in the workplace.

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Biographies

Catherine T. Amelink, Ph.D., serves as the Associate Vice Provost in the Office of the Executive Vice Provost. In this role she facilitates the university-wide Destination Area initiative, an effort to advance transdisciplinary research and learning that will address complex problems that impact the human condition and also develop complex problem solving skills among students. She works with units on campus to design, implement, and evaluate innovative learning experiences that support strategic goals related to experiential learning and distance learning and works closely with faculty members on grants that are designed to advance student learning. Her collective experience includes positions that have played an active role in educational policy and practice at the K12, department, university, and state level. Her research has focused on efficacy of learning approaches and in particular the impact of learning approaches on underrepresented groups in STEM. Her publications have appeared in several peer reviewed journals, including the Journal of Engineering Education, the Journal of Women and Minorities in Science and Engineering, the Journal of Women in Higher Education, Advances in Engineering Education and the Journal of Community College Research and Practice. She is an affiliate faculty in both the Higher Education program in the School of Education and the Department of Engineering Education in the College of Engineering at Virginia Tech.

G. Don Taylor, Ph.D., currently serves as the Executive Vice Provost at Virginia Tech. Dr. Taylor's research interests focus on the simulation of complex systems and the logistics of material flow and freight transportation. He has served as Principal Investigator or Co-Principal Investigator on more than 60 externally funded projects. His research has led to the publication of 10 edited books, more than 75 journal articles and book chapters, and more than 120 conference papers and technical reports. Prof. Taylor has made more than 200 formal presentations at conferences or seminars and has had research relationships with more than 50 different companies. He is a Fellow and a Past-President and Member of the Board of Trustees of the Institute of Industrial and Systems Engineers (IISE). He is currently Chairperson of the Board of IISE Solutions, Inc. He is also a Fellow and Member of the Board of the World Academy of Productivity Science, and is a registered Professional Engineer.