Student Engagement and Training in Healthcare Engineering with Advanced Data Analytics Solutions

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NSF IUSE: Student Engagement and Training in Healthcare Engineering with Advanced Data Analytics Solutions

Abstract

This paper presents the design, implementation, and evaluation of a multi-course curricular transformation and outreach initiative to align undergraduate and graduate engineering education with evolving healthcare workforce demands. Three restructured courses, Decision Support Systems in Healthcare Systems, Computer Simulation Applications for Healthcare Systems, and Introduction to Data Mining for Healthcare, were complemented by community outreach activities, including high school workshops and a Family Café. The project integrates data analytics, discrete-event simulation, and digital decision-making tools using Excel/VBA, SQL, FlexSim, and Python. A structured pedagogical framework grounded in Bloom's taxonomy and experiential learning guided learning outcome development. Mixed-method pre- and post-assessments demonstrated statistically meaningful gains in student confidence, technical proficiency, problem-solving ability, and healthcare application competence. The initiative aligns closely with NSF IUSE goals by improving student learning, broadening participation, strengthening experiential learning, and promoting scalable curricular innovation. Results demonstrate a sustainable and transferable model for healthcare-focused engineering education.

Keywords: STEM Education, Data Analytics, Healthcare Systems, Education Research

1. Introduction

Healthcare systems are undergoing rapid transformation driven by rising operational complexity, workforce shortages, increasing data availability, and growing expectations for quality, safety, and efficiency. Hospitals and healthcare providers now rely heavily on data analytics, simulation modeling, and digital decision-support tools to improve patient flow, optimize staffing, manage supply chains, and support evidence-based decision-making [1]. Consequently, the modern healthcare engineering workforce requires strong competencies in computational modeling, data analytics, systems thinking, interdisciplinary communication, and responsible data use [2]. Today healthcare workforce must be able to integrate heterogeneous clinical and operational data, build predictive and prescriptive models, and translate quantitative insights into actionable recommendations for clinicians and administrators [3].

Despite these evolving demands, many traditional engineering programs remain insufficiently aligned with healthcare practice. Curricula often emphasize tool proficiency in isolation rather than integrated, domain-driven problem solving. Students may gain exposure to simulation or data analytics without engaging authentic healthcare datasets, operational constraints, regulatory considerations, or interdisciplinary collaboration. As a result, graduates frequently lack confidence in applying technical skills to healthcare contexts, limiting workforce readiness and slowing the adoption of advanced engineering methods in healthcare delivery systems [4].

To address this gap, this project, *Student Engagement and Training in Healthcare Engineering with Advanced Data Analytics Solutions*, restructured three core courses and established a Healthcare Data Analytics (HDA) learning ecosystem at The University of Texas at El Paso (UTEP). The initiative integrates data analytics, discrete-event simulation, and experiential learning across undergraduate and graduate levels while strengthening pre-college and community engagement pipelines. This paper presents the pedagogical framework, implementation approach, assessment methodology, and observed outcomes of this effort.

2. Background and Motivation

The healthcare industry increasingly demands engineers who can design, analyze, and optimize complex socio-technical systems [5]. Operational challenges such as emergency department congestion, staffing shortages, patient throughput variability, and supply chain disruptions require modeling and analytics capabilities that extend beyond traditional operations research formulations. Healthcare organizations are adopting digital twins, predictive analytics, and simulation-based optimization to test policies before deployment and to support real-time operational decision-making [6-8]. These trends necessitate graduates who are fluent not only in computational tools but also in healthcare domain reasoning, data governance, and interdisciplinary communication.

However, conventional engineering curricula frequently fall short in several respects. Instruction is often siloed by discipline, with limited cross-course integration and minimal exposure to authentic healthcare problems. Programming and analytics skills are commonly taught abstractly, with insufficient scaffolding for application, leading to cognitive overload when students encounter real datasets. Moreover, undergraduate and graduate programs are rarely aligned intentionally, resulting in discontinuity between foundational skill development and advanced research engagement. Finally, limited early outreach restricts awareness among underrepresented populations regarding healthcare engineering pathways.

This initiative aligns strongly with the goals of the NSF IUSE by strengthening evidence-based instructional practices, broadening participation among historically underserved students, embedding experiential learning, and developing scalable curricular models. The project's emphasis on modular course redesign, reusable datasets, and community partnerships supports sustainability and transferability beyond the award period.

3. Project Design and Pedagogical Approach

The curricular redesign was guided by an integrated pedagogical framework combining Bloom's taxonomy [9], experiential learning theory [10], and systems thinking [11], as shown in Figure 1. Learning outcomes were explicitly mapped to Bloom's higher cognitive levels (Apply, Analyze, and Evaluate) to ensure that students moved beyond procedural use of tools toward analytical reasoning and decision-making. Experiential learning was operationalized through project-based assignments using authentic healthcare datasets and professional software platforms. Systems thinking was reinforced by requiring students to model end-to-end workflows rather than isolated components.

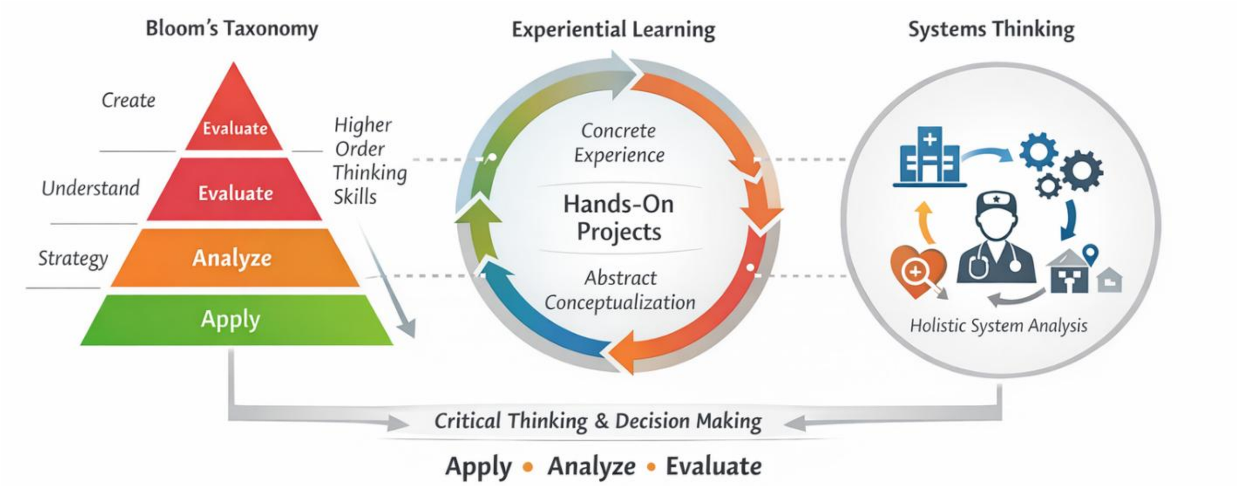

Figure 1. Pedagogical framework for project implementation

Three courses were restructured to form a coherent learning pathway. The Decision Support Systems in Healthcare Systems course emphasizes spreadsheet modeling, VBA automation, SQL databases, and dashboard development applied to hospital and healthcare supply chain datasets. Students analyzed hospital data and patient records to construct functional decision-support tools that support managerial interpretation. The Computer Simulation Applications for Healthcare Systems course focuses on discrete-event simulation of emergency departments using FlexSim, where students model patient arrivals, triage processes, staffing configurations, and resource utilization to identify bottlenecks and test improvement strategies. The Introduction to Data Mining for Healthcare course introduces supervised and unsupervised learning, predictive modeling, and system emulation using Python and Jupyter notebooks, culminating in independent healthcare analytics projects.

Vertical alignment between undergraduate and graduate education was achieved through shared datasets, modeling frameworks, and mentoring structures. Graduate students served as facilitators and project mentors, while advanced students engaged in deeper model validation, algorithm tuning, and research dissemination. This structure ensured continuity from foundational skill acquisition to research-level application.

In addition to curricular innovation, the project implemented multiple outreach activities. High school students participated in immersive workshops covering simulation, machine learning, 3D printing, and AR/VR, fostering early exposure to engineering pathways. The Family Café engaged parents and guardians in understanding healthcare engineering careers and academic pathways, strengthening community support systems. These activities directly support recruitment, retention, and diverse objectives.

4. Assessment Methodology

A mixed-methods evaluation framework was adopted to measure learning effectiveness and program impact. Quantitative data were collected through pre- and post-surveys using a 5-point Likert scale to assess technical proficiency, confidence, problem-solving ability, communication, teamwork, and competence in healthcare applications. Qualitative data were gathered through open-ended survey responses and exit interviews. Each course administered baseline and end-of-term surveys, while outreach activities employed pre- and post-event instruments.

The Decision Support Systems course enrolled 72 students, of whom 58 completed post-surveys. The Simulation course enrolled 22 senior undergraduates. The Data Mining course enrolled 11 students, of whom 7 completed post-surveys. High school workshops involved 22 participants, and Family Café assessments included students and family members. This triangulated approach ensured reliability across instructional and outreach contexts.

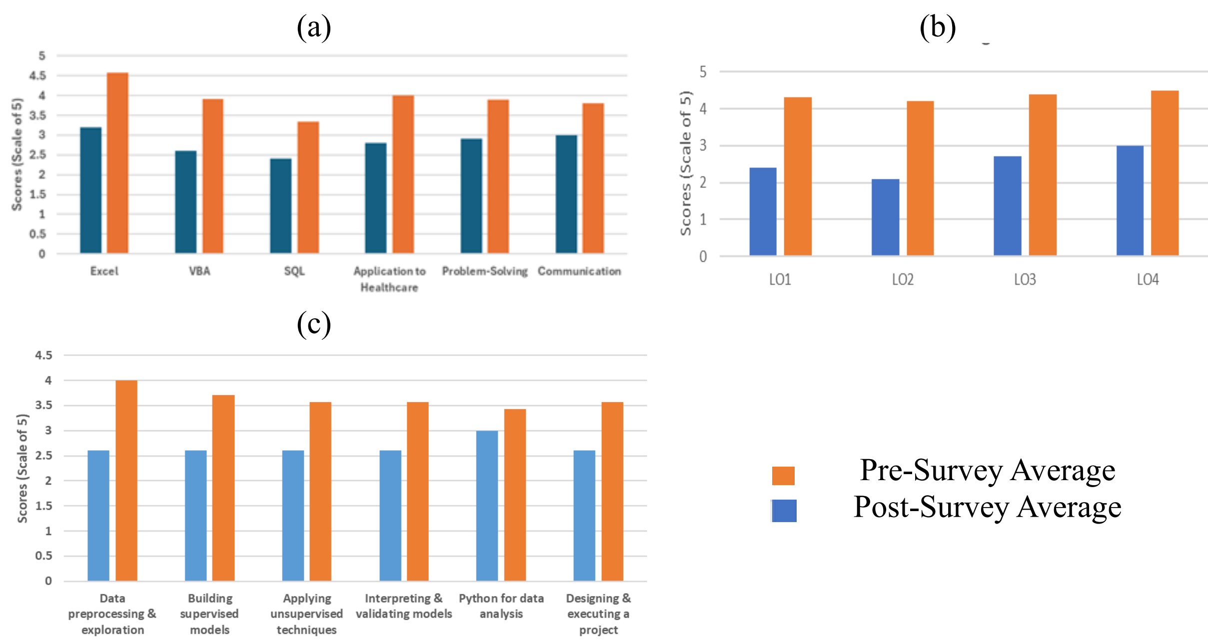

Figure 2. Assessment of student learning outcomes (a) Decision Support Systems course, (b) Computer Simulation Course, and (c) Data Mining course

5. Observations and Findings

Quantitative results indicate substantial gains across all three courses. In the Decision Support Systems course, student confidence in Excel increased from 3.2 to 4.57, VBA from 2.6 to 3.91, SQL from 2.4 to 3.33, and healthcare application from 2.8 to 4.0. 95% of students reported improved analytical skills, and 93% indicated they would recommend the course. Nearly 78%

reported increased interest in healthcare systems. In the Simulation course, aggregate learning outcomes increased from an average of 2.6 to 4.35 across simulation concepts, healthcare application, problem-solving, and teamwork. 95% reported improved ability to apply simulation in healthcare contexts. Students demonstrated stronger capability in bottleneck analysis, “what-if” experimentation, and model validation. In the Data Mining course, average confidence across six skill areas reached 3.64, with the strongest gains in data preprocessing (4.0) and supervised learning (3.71). The assessment results for the learning outcomes are shown in Figure 2.

Outreach activities also demonstrated a strong impact. High school workshop participants rated learning experiences highly, with average scores of 4.5–4.7 across simulation, machine learning, AR/VR, and 3D printing domains. 100% agreed that the workshop increased motivation for college education. Family Café participants reported significant increases in familiarity with industrial and healthcare engineering, with over 93% rating the workshop as important or very important and a strong intent to attend future events. Substantial gain was operationalized as a mean Likert increase greater than 1.0, agreement levels above 80%, and corroborating qualitative feedback. All instructional components exceeded these thresholds, indicating meaningful educational impact.

6. Discussion and Conclusion

The results demonstrate that contextualized, experiential instruction significantly enhances student confidence, technical proficiency, and healthcare relevance. Integrating analytics and simulation across multiple courses reduces cognitive fragmentation and strengthens system-level reasoning. Vertical alignment between undergraduate and graduate education supports sustained skill progression and research readiness. Outreach activities extend impact beyond the university, strengthening equity-driven pipelines and family engagement. Challenges included steep learning curves in programming-intensive modules and time constraints in compressed course formats. These challenges inform future scaffolding strategies and refinements to modular pacing.

This project demonstrates a sustainable, scalable model for aligning engineering education with healthcare workforce needs through integrated analytics, simulation, experiential learning, and community engagement. Quantitative assessment confirms substantial gains in student competence and confidence, while outreach initiatives strengthen early awareness and inclusion. Alignment with NSF IUSE goals positions the model for replication across institutions. Continued refinement and dissemination will further enhance workforce preparedness and interdisciplinary capacity in healthcare engineering.

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