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Inclusive Design for Intellectual Disabilities: Bridging the Gaps in Engineering and Empowering Future Engineers

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Dr. Douglas Yung is an Associate Teaching Professor and Program Director in the bioengineering undergraduate program at Syracuse University, where he has made a significant impact through his teaching, research, and community outreach efforts. With a research focus on interfacing microbes with engineering tools at the micro- and nano-scale, Dr. Yung is exploring methods to rapidly assess the viability of superbugs and harness energy from extremophiles using advanced electrochemical, optical, and MEMS devices. A champion of diversity and equity in engineering education, Dr. Yung has designed innovative curricula that integrate project-based learning, hands-on activities, and peer collaboration. He is a strong advocate for incorporating disability perspectives in biomedical engineering, aiming to train a generation of engineers who are equipped to tackle accessibility challenges in healthcare technology. Dr. Yung's commitment to STEM outreach is evidenced by his extensive work with underrepresented K-12 students in Central New York. Through various programs, including those at La Casita Cultural Center and local schools, he has fostered a love for science and engineering in young minds, providing over 300 hours of instruction. His dedication to equitable education extends to developing initiatives that engage students from all backgrounds, and his efforts have earned him the Chancellor's Excellence in Citation Award at Syracuse University. In addition to his academic duties, Dr. Yung is an active leader in promoting humanitarian engineering, emphasizing the importance of socially inclusive and sustainable engineering solutions in his teaching. He has collaborated on various projects aimed at addressing the needs of marginalized communities and has led numerous outreach activities to expose high school students to biomedical engineering. Dr. Yung's contributions to education and outreach have been widely recognized, including receiving the College Educator of the Year Award (2022) and STEM Outreach Award (2024) by the Technology Alliance of Central New York.

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Abstract

The underrepresentation of individuals with intellectual disabilities in engineering design reveals critical gaps in both education and practice. Addressing these disparities, this study introduces the INCLUDE Framework (Innovation, Needs-driven design, Collaboration, Learning through Empathy, User-centered solutions, and Diversity-driven Education), a transformative educational model that integrates multidisciplinary collaboration, empathy-driven learning, and innovative assessment tools. Through immersive, real-world learning experiences and interdisciplinary team projects, the framework empowers future engineers to create inclusive, user-centered solutions that address cognitive and social challenges often overlooked in traditional curricula.

Implemented across multiple undergraduate and graduate-level engineering courses, the INCLUDE Framework demonstrated measurable gains in empathy development, multidisciplinary collaboration, and inclusive design competencies. Students reported significant improvements in user-centered design skills, while project outcomes achieved high usability and satisfaction ratings among end users and disability advocates. Data analysis revealed strong correlations between empathy, collaboration, and project success, highlighting the critical role of holistic assessment strategies.

This study underscores the importance of embedding inclusivity into engineering education to prepare socially responsible engineers capable of addressing diverse societal needs. The findings offer a scalable model for curricular integration, advancing equity and accessibility in engineering through inclusive design practices.

Introduction

Despite representing approximately 2–3% of the global population, individuals with intellectual disabilities remain largely invisible in engineering design, with critical gaps in education and practice perpetuating systemic inequities [1]. Several studies highlight the broader challenges faced by this population in STEM education and higher education. For instance, a study published in Educational Researcher found that minority students are disproportionately underrepresented in special education, including programs that could lead to STEM fields [2], [3]. Additionally, research on inclusive higher education programs indicates that students with intellectual disabilities often lack access to postsecondary education opportunities, limiting their participation in fields like engineering [4]. These systemic barriers contribute to the underrepresentation of individuals with intellectual disabilities in engineering design and related disciplines, further reinforcing inequities. Addressing these gaps requires a concerted effort to create inclusive educational environments that support the participation of individuals with intellectual disabilities in all aspects of STEM, including engineering design.

The underrepresentation of intellectual disabilities in engineering design poses a significant challenge for engineering education. While physical disabilities often receive attention due to their visibility and established accessibility standards, intellectual disabilities remain

marginalized. Addressing these gaps requires nuanced approaches to meet the cognitive and social complexities involved, which are often overlooked in engineering curricula. As a result, critical user needs remain unaddressed, perpetuating stereotypes and systemic inequities in inclusive design.

Research underscores this disparity, revealing a lack of focus on intellectual disabilities compared to mobility or sensory impairments. A systematic review of engineering programs found minimal integration of intellectual disabilities in course content, with user-centered design approaches disproportionately prioritizing physical accessibility [1], [2]. Case studies frequently emphasize mobility-related solutions, leaving cognitive and social challenges insufficiently addressed [3]. This imbalance highlights an urgent need for engineering education to move beyond traditional technical approaches and embrace inclusivity as a core principle.

To address these gaps, this study introduces the INCLUDE Framework, a transformative approach that integrates Innovation, Needs-driven design, Collaboration, Learning through Empathy, User-centered solutions, and Diversity-driven Education. The INCLUDE Framework equips future engineers with tools and perspectives to design impactful solutions for individuals with intellectual disabilities by emphasizing three key components:

- Multidisciplinary Collaboration: Encourages engineering students to work alongside healthcare professionals, sociologists, and disability advocates to address complex challenges with diverse perspectives.
- Empathy-Driven Learning: Promotes immersive experiences, enabling students to connect with the lived experiences of individuals with intellectual disabilities and translate these insights into user-centered designs.
- Innovative Assessment Tools: Captures the multifaceted outcomes of inclusive design projects by evaluating technical feasibility, social impact, and user satisfaction.

The objectives of this study are twofold. First, it seeks to empower engineering students to develop inclusive design solutions through collaboration and empathy. Second, it introduces assessment strategies to ensure that student designs align with real-world user needs. By embedding the INCLUDE Framework into engineering curricula, this work bridges the gap between technical expertise and social responsibility, fostering a new generation of engineers equipped to address diverse societal challenges through inclusive design.

Proposed Framework: The INCLUDE Approach

The INCLUDE Framework (Innovation, Needs-driven design, Collaboration, Learning through Empathy, User-centered solutions, and Diversity-driven Education) offers a transformative approach to integrating intellectual disabilities into engineering education. It emphasizes three interconnected pillars: Multidisciplinary Collaboration, where diverse teams of engineers, healthcare professionals, sociologists, and disability advocates co-create holistic solutions; Empathy-Driven Learning, which fosters understanding through immersive experiences, user engagement, and reflective practices; and Innovative Assessment Tools, which evaluate technical feasibility, collaboration, empathy, and social impact using metrics like

empathy mapping, participatory evaluation, and user feedback. Together, these components prepare engineers to design inclusive, impactful solutions that address real-world challenges with technical rigor and social responsibility. Figure 1 provides a visual representation of the core pillars and their interconnections, while Table 1 contrasts the INCLUDE Framework with traditional engineering education to highlight its transformative approach.

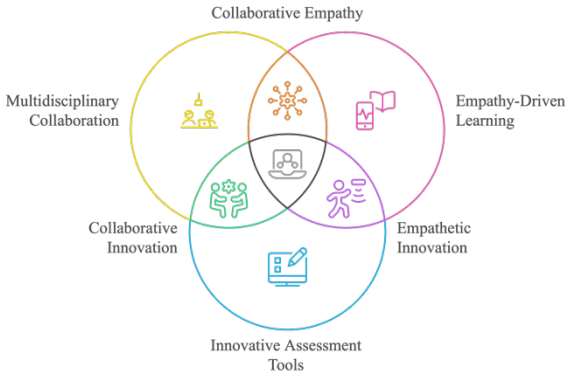

Figure 1 The INCLUDE Framework (Innovation, Needs-driven design, Collaboration, Learning through Empathy, User-centered solutions, and Diversity-driven Education) offers a transformative approach to integrating intellectual disabilities into engineering education.

Aspect	**Traditional Engineering Education**	**INCLUDE Framework**
User Engagement	Limited user involvement; users are often consulted only during the final stages of design or for validation.	Direct and continuous user engagement through immersive experiences such as sensory simulations, user interviews, and co-design workshops, allowing engineers to deeply understand the lived experiences and needs of diverse users, including those with intellectual disabilities.
Collaboration	Engineering teams only; collaboration is limited to technical disciplines, often lacking integration of social perspectives.	Multidisciplinary teams comprising engineers, healthcare professionals, sociologists, and disability advocates. This approach ensures diverse expertise and perspectives are incorporated, fostering holistic solutions that address technical, social, and cultural dimensions.
Assessment	Primarily focused on technical metrics such as efficiency, accuracy, and feasibility, with limited consideration of societal impact.	Holistic assessment that includes empathy, collaboration, and social impact alongside technical metrics. Tools like empathy mapping, participatory evaluation, and structured co-design workshops ensure solutions are evaluated for inclusivity, user satisfaction, and real-world applicability.
Outcome	Feasible but often less inclusive designs that may not fully address user needs or societal challenges.	Inclusive, impactful, and user-centered solutions that balance technical rigor with social responsibility. Outcomes are tailored to real-world challenges and designed to empower underrepresented and diverse user groups, fostering accessibility and equity.

Skill Development	Focused on technical skills with minimal emphasis on interpersonal, empathy, or reflective practices.	Emphasizes empathy-driven learning, reflective practices, and real-world problem-solving. Students develop both technical expertise and social awareness, preparing them to design solutions with broader societal and ethical implications.
Pedagogical Approach	Primarily lecture-based with limited experiential learning or interdisciplinary engagement.	Combines immersive learning, problem-based learning (PBL), and interdisciplinary projects. Students engage in iterative co-design and reflective exercises, bridging the gap between theoretical knowledge and practical application in diverse contexts.

Table 1. Comparison of Traditional Engineering Education and the INCLUDE Framework, highlighting key differences in user engagement, collaboration, assessment, outcomes, skill development, and pedagogical approach. The INCLUDE Framework emphasizes multidisciplinary collaboration, empathy-driven learning, and holistic assessment to prepare engineers for designing inclusive, impactful, and user-centered solutions.

Multidisciplinary Collaboration

Multidisciplinary collaboration lies at the core of the INCLUDE Framework, fostering a holistic approach to solving complex challenges. By bringing together diverse expertise, this methodology ensures that innovative and inclusive solutions emerge through the integration of varied perspectives.

Engineering problems are often multifaceted, requiring input from multiple disciplines to address technical, social, and cultural dimensions effectively. Multidisciplinary collaboration leverages the collective expertise of individuals from diverse fields such as engineering, healthcare, sociology, and advocacy. This approach not only enriches the design process but also ensures that solutions are both technically sound and socially impactful. As global challenges grow increasingly complex, the role of multidisciplinary teams in solving these problems has become indispensable.

Studies highlight the transformative potential of multidisciplinary collaboration in creating impactful solutions [5]. Functional diversity within teams fosters innovation, particularly when supported by transformational leadership that encourages collaboration and values diverse perspectives. Studies using decision tree algorithms reveal that diversity in research teams significantly enhances innovative performance, especially in complex fields such as artificial intelligence. Computational approaches to team assembly further demonstrate that leveraging social networks can optimize team composition, amplifying both innovation and problem-solving capabilities [6], [7], [8]. Notable examples include assistive technologies co-designed by engineers, clinicians, and end users, which have achieved significant advancements in accessibility and user experience. These findings emphasize the critical role of integrating diverse perspectives to address user needs comprehensively and holistically.

The INCLUDE Framework operationalizes multidisciplinary collaboration by structuring diverse teams of students, professionals, and advocates to work on real-world challenges. The methodology involves:

- **Team Composition**: Engineering students collaborate with healthcare professionals, sociologists, and disability advocates to ensure a broad spectrum of expertise.
- **Iterative Co-Design**: Teams engage in cycles of prototyping and feedback, incorporating insights from all stakeholders.
- **Role-Based Learning**: Participants take on specific roles, such as technical leads or user advocates, to ensure balanced contributions and accountability.

This structured approach ensures that collaboration extends beyond mere interaction, fostering genuine integration of knowledge and perspectives. By emphasizing open communication, shared goals, and iterative feedback, the INCLUDE Framework prepares participants to tackle complex, real-world challenges with creativity and empathy.

Empathy-Driven Learning

Empathy-driven learning is the heart of the INCLUDE Framework, enabling engineers to connect deeply with the individuals they aim to serve. This methodology equips students to understand the cognitive and social complexities faced by individuals with intellectual disabilities and translate these insights into user-centered designs.

Empathy-driven learning stems from the broader educational principle that understanding the lived experiences of users enhances design quality and relevance. Engineering solutions are often constrained by designers' limited perspectives, which can lead to misaligned or impractical outcomes. Empathy-driven learning addresses this gap by fostering a deeper connection between designers and end users through experiential and reflective practices. This approach not only improves technical designs but also instills a sense of social responsibility in engineering students.

Research highlights the effectiveness of empathy-driven learning in enhancing both educational outcomes and design impact. In engineering education, developing empathy significantly improves students' ability to understand user needs, resulting in more user-centered and innovative solutions. Studies demonstrate that incorporating empathy-focused instruction into the design thinking process, alongside effective pedagogical techniques, fosters deeper engagement, improved usability, and better design outcomes across diverse educational contexts. This underscores the importance of empathy as a critical skill for engineering students aiming to create impactful, user-oriented solutions [9], [10], [11]. Successful programs often include participatory activities, such as user interviews and immersion exercises, which have been instrumental in developing accessible and inclusive assistive technologies. These findings emphasize the value of making empathy a core element of engineering education.

The INCLUDE Framework operationalizes empathy-driven learning through a structured methodology that includes:

- **Immersive Experiences**: Students participate in activities such as sensory simulations and direct engagement with individuals with intellectual disabilities to gain firsthand knowledge of user needs.
- **Reflective Practices**: Tools like journaling, group discussions, and guided reflection sessions help students process their experiences and extract actionable design principles.
- **Problem-Based Learning (PBL)**: Real-world challenges form the basis of student projects, encouraging them to critically analyze user requirements and apply their skills to develop meaningful solutions.

This structured methodology ensures that students not only develop technical expertise but also cultivate the empathy needed to design solutions that are inclusive, impactful, and aligned with real-world user needs.

Innovative Assessment Tools

Innovative assessment tools are crucial for evaluating the multifaceted outcomes of inclusive design projects. Traditional technical metrics alone are insufficient to capture the broader impacts of engineering solutions, such as collaboration, empathy, and social responsibility. These tools aim to provide a holistic evaluation framework that aligns with the principles of inclusive engineering education.

Assessment in engineering education has traditionally focused on technical accuracy and efficiency, often overlooking the social and ethical dimensions of design. For example, a study by Walther et al. (2016) highlights that conventional assessments rarely evaluate teamwork or empathy, which are critical for addressing complex societal challenges [12]. However, inclusive engineering practices require metrics that assess how well solutions address user needs, promote teamwork, and demonstrate empathy. By integrating diverse evaluation methodologies, innovative assessment tools provide a more comprehensive understanding of both the technical and societal impacts of engineering designs.

The use of innovative assessment tools in education has been linked to significant improvements in learning outcomes and project effectiveness [13]. Similarly, empathy mapping frameworks have been shown to enhance students' ability to understand and respond to complex user needs, resulting in more inclusive and practical solutions [14]. These examples highlight the transformative potential of assessment tools that go beyond traditional metrics.

The INCLUDE Framework employs a structured methodology to integrate innovative assessment tools into engineering education:

- **Empathy Mapping Frameworks**: Students use visual tools to document user needs, preferences, and challenges, ensuring that designs are grounded in real-world experiences.
- **Participatory Evaluation Models**: Users and advocates are actively involved in providing feedback throughout the design process, fostering iterative improvements and enhancing user-centricity.

- **Structured Co-Design Workshops**: Dynamic workshops facilitate collaboration between students and users, allowing for real-time feedback and refinement of solutions.

This approach ensures that assessment not only measures technical feasibility but also evaluates the social and collaborative dimensions of design. By embedding these tools into the curriculum, the INCLUDE Framework prepares students to address real-world challenges with a balanced focus on technical excellence and societal impact. The key strategies and tools that underpin the INCLUDE Framework, as well as their associated outcomes, are summarized in Table 2. This table provides a detailed roadmap for implementing the framework's core components in educational and real-world contexts.

Component	Strategies/Tools	Outcomes
Multidisciplinary Collaboration	- Cross-Functional Teams: Students collaborate with engineers, healthcare professionals, sociologists, and disability advocates to integrate diverse expertise. - Co-Design Workshops: Teams engage in iterative prototyping and receive real-time feedback from users and stakeholders. - Role-Based Learning: Participants assume specific roles (e.g., technical lead, user advocate) to ensure balanced contributions and accountability.	- Diverse Perspectives: Solutions address technical, cultural, and social dimensions holistically. - Holistic Solutions: Designs meet complex user needs and promote accessibility and inclusivity.
Empathy-Driven Learning	- Immersive Experiences: Sensory simulations, user interviews, and direct engagement with individuals with intellectual disabilities. - Reflective Exercises: Tools such as journaling, guided group discussions, and empathy mapping foster deeper understanding of user needs. - Problem-Based Learning (PBL): Real-world challenges encourage students to analyze user requirements and develop meaningful solutions	- Ethical Awareness: Engineers develop a sense of social responsibility and inclusivity. - Socially Aware Designs: User needs are integrated into every step of the design process, enhancing relevance and usability.
Innovative Assessment Tools	- Empathy Mapping Frameworks: Visual tools to document user needs, preferences, and challenges, ensuring that designs are grounded in real-world experiences. - Participatory Evaluation Models: Users provide feedback at every design iteration, ensuring inclusivity and user-centricity. - Structured Co-Design Workshops: Dynamic sessions where students collaborate with users to refine designs based on real-time input.	- User-Centered Metrics: Evaluation focuses on usability, accessibility, and user satisfaction alongside technical feasibility. - Enhanced Technical/Social Outcomes: Solutions are effective, inclusive, and address real-world challenges.
Skill Development	- Interdisciplinary Skills: Training in teamwork, communication, and the integration of technical and social knowledge. - Empathy as a Core Competency: Structured activities and assessments build emotional intelligence alongside technical skills.	- Well-Rounded Engineers: Graduates are prepared to tackle complex societal challenges with both technical expertise and empathy. - Sustainable Impact: Solutions have lasting effects by

	- Inclusive Design Thinking: Students learn frameworks for designing with marginalized or underrepresented groups in mind.	addressing root causes and user challenges comprehensively.
Framework Application	- Iterative Design Cycles: Students test prototypes in real-world scenarios, gather feedback, and refine solutions. - Integration into Curricula: The framework is embedded into engineering education programs through courses, projects, and capstone experiences. - Collaboration with Community Partners: Partnerships with disability advocates and organizations ensure relevance and real-world impact.	- Practical Readiness: Students gain experience in implementing designs in real-world settings. - Community Engagement: Strong partnerships lead to solutions that directly benefit the intended users and broader society.

Table 2: Expanded overview of the INCLUDE Framework, detailing the strategies, tools, and expected outcomes for its core components: Multidisciplinary Collaboration, Empathy-Driven Learning, and Innovative Assessment Tools. The table also highlights skill development and practical application to showcase the framework's transformative potential in engineering education.

The INCLUDE Framework represents a paradigm shift in engineering education, addressing critical gaps in the curriculum by integrating multidisciplinary collaboration, empathy-driven learning, and innovative assessment tools. By preparing future engineers to design solutions that balance technical rigor with social responsibility, the framework not only enhances the inclusivity of engineering practices but also equips students to tackle real-world challenges with a holistic perspective. This transformative approach ensures that engineering education evolves to meet the needs of an increasingly diverse and interconnected world.

Methodology

The INCLUDE Framework has been applied across various engineering classes, engaging students with diverse academic standings, from undergraduates to graduate students. The framework has been implemented in undergraduate engineering capstone design projects, independent study projects, and graduate-level engineering ethics courses. This section details the methodology for integrating the INCLUDE Framework into these educational settings, focusing on multidisciplinary collaboration, empathy-driven learning, and innovative assessment tools.

Framework Integration

Multidisciplinary collaboration lies at the core of the INCLUDE Framework, fostering holistic design solutions by incorporating diverse perspectives. Teams composed of engineering students, healthcare professionals, sociologists, and disability advocates were formed to address real-world challenges related to intellectual disabilities. These teams were tasked with designing assistive devices and systems tailored to the cognitive, social, and physical needs of users. The

collaboration emphasized iterative co-design workshops and role-based learning exercises, ensuring balanced contributions and accountability among team members.

Empathy-driven learning activities enabled students to connect deeply with users, translating their insights into user-centered designs. Through immersive experiences such as sensory simulations and direct user engagement, students developed a nuanced understanding of the lived experiences of individuals with intellectual disabilities. Problem-Based Learning (PBL) modules provided opportunities to address real-world challenges and encouraged reflective thinking through journaling and guided discussions.

Innovative assessment tools further enhanced the learning process by capturing holistic metrics beyond technical feasibility. Empathy mapping exercises and structured co-design workshops allowed teams to iteratively gather and incorporate user feedback, ensuring designs met both technical and social criteria. Quantitative metrics such as collaboration and empathy scores, collected via Likert scale surveys, and qualitative metrics, including reflection journals and thematic analyses, provided comprehensive evaluations of the framework's effectiveness.

Intervention Activities

Intervention activities were designed to provide students with meaningful, hands-on experiences that aligned with the INCLUDE Framework. Immersive experiences involved students participating in sensory simulations and engaging directly with individuals with intellectual disabilities to gain firsthand insights. Role-playing and PBL further reinforced the importance of collaboration and empathy, with students adopting specific roles such as technical lead or user advocate to balance team dynamics and contributions.

Reflection and journaling activities helped students process their experiences and translate them into actionable insights, fostering critical thinking and ethical awareness. Teams engaged in iterative prototyping, presenting their designs to stakeholders, gathering feedback, and refining solutions. These activities ensured that students' projects were not only technically sound but also socially impactful.

Assessment Plan

Assessment of the INCLUDE Framework employed both quantitative and qualitative methods to ensure robust evaluations. The tables below (Table 3 and Table 4) provide a detailed breakdown of the assessment tools, metrics, and their alignment with the framework's goals.

Table 3: Quantitative Metrics and Tools for Assessing the INCLUDE Framework

Aspect	Metric	Description	Tool
Collaboration	Peer-reviewed scores	Evaluates team dynamics, equal contributions, and communication effectiveness.	Likert scale surveys (1-5)

Empathy	Pre/post empathy survey	Assesses growth in understanding user needs before and after immersive experiences.	Standardized empathy questionnaires
User-centered Design	Usability and satisfaction ratings	Captures feedback on the usability and relevance of designed solutions.	Structured feedback questionnaires
Social Impact	Impact assessment ratings	Measures perceived societal benefit and alignment with user needs.	User interviews and surveys
Iterative Design	Prototype refinement rates	Tracks the number of iterations and improvements made based on stakeholder feedback.	Stakeholder feedback forms

Table 4: Qualitative Metrics and Tools for Assessing the INCLUDE Framework

Aspect	**Metric**	**Description**	**Tool**
Empathy	Thematic reflection analysis	Analyzes depth of reflection and insights gained from user interactions.	Journaling, focus group discussions
Collaboration	Observations on team dynamics	Documents the effectiveness of multidisciplinary collaboration and role integration.	Video analysis, observational notes
User Feedback	Iterative feedback insights	Captures detailed feedback from users on prototypes and their alignment with needs.	Participatory evaluation sessions
Design Process	Design documentation analysis	Reviews how well the design process aligns with empathy and user-centered principles.	Process journals, design portfolios
Social Impact	Stakeholder thematic feedback	Explores broader impacts of the design on community and user well-being.	Interviews with users and community partners

Data Analysis

Data analysis ensured the rigorous evaluation of the INCLUDE Framework. Quantitative data, such as changes in empathy and collaboration scores, were analyzed using paired t-tests and ANOVA to assess the impact of the framework on student learning and project outcomes. Improvements in user satisfaction and usability ratings were tracked across iterative design cycles.

Qualitative data were analyzed through thematic coding of reflection journals, observational notes, and feedback from participatory evaluation sessions. This analysis highlighted key areas for improvement and informed actionable recommendations for enhancing the framework's implementation in future iterations.

Continuous Improvement

The INCLUDE Framework integrates iterative feedback loops, allowing for continuous refinement of strategies and assessment tools. Feedback from users, team performance metrics, and social impact evaluations were systematically incorporated into subsequent course cycles. This adaptive approach ensured that the framework remained relevant and effective in addressing the needs of individuals with intellectual disabilities while fostering socially responsible engineering practices.

Results

Empathy Development

Empathy development among students was a central focus of the INCLUDE Framework, aimed at fostering deeper understanding and connection with individuals with intellectual disabilities. The immersive activities and reflective practices were designed to enhance students' awareness of the lived experiences and challenges faced by this population.

The pre-activity and post-activity empathy scores were assessed using a 5-point Likert scale, where higher scores indicated greater empathy. Students reported a significant increase in empathy following their participation in sensory simulations and direct engagement activities.

Pre-activity mean empathy score: 3.2 ± 0.6
Post-activity mean empathy score: 4.6 ± 0.4
Statistical significance: $p < 0.01$ (paired t-test)

The increase in empathy scores suggests that experiential learning activities were highly effective in enhancing students' understanding of user needs.
Reflection journals and guided discussions revealed recurring themes that supported the quantitative findings. Students frequently noted how the immersive activities reshaped their perceptions of designing for individuals with intellectual disabilities.

Key themes identified from qualitative analysis included:

1. Heightened Awareness of User Needs: Students expressed a deeper appreciation for the complexity of cognitive and social challenges.
    - Sample quote: "The sensory simulation helped me understand how overwhelming everyday tasks can be. It made me rethink how to simplify designs for users."

2. Shifting Perspectives on Design: Many participants highlighted the importance of incorporating empathy as a core design principle.
    - Sample quote: "Interacting with users helped me see beyond the technical aspects, understanding the emotional and functional impacts of our designs."

3. Commitment to Inclusive Design: Students demonstrated a strong desire to integrate user-centered approaches into their future engineering work.

- Sample quote: “This experience has changed how I view engineering. It’s not just about solving technical problems but also about improving lives.”

The combination of immersive experiences and reflective practices significantly enhanced empathy development among students, as evidenced by both the quantitative and qualitative results. These findings underscore the importance of empathy-driven learning in engineering education, demonstrating its potential to prepare students for designing impactful, user-centered solutions.

Collaboration Metrics

Collaboration across multidisciplinary teams was a key component of the INCLUDE Framework, designed to encourage diverse perspectives and foster holistic solutions. Teams composed of engineering students, healthcare professionals, sociologists, and disability advocates worked together to address real-world challenges related to intellectual disabilities.

Collaboration metrics were assessed using self-assessment surveys and peer review feedback. Results showed that multidisciplinary teams consistently achieved higher collaboration scores compared to single-discipline teams.

Average collaboration score for multidisciplinary teams: 4.5 ± 0.3
Average collaboration score for single-discipline teams: 3.8 ± 0.5
Statistical significance: $t(18) = 4.2$, $p < 0.01$

Students in multidisciplinary teams reported improved communication, creativity, and the integration of diverse perspectives, highlighting the value of cross-functional collaboration.

Peer feedback and observational notes provided rich insights into the dynamics of multidisciplinary collaboration. Key themes included:

1. Enhanced Creativity and Problem-Solving: Students noted that working with individuals from different disciplines enriched their brainstorming and led to more innovative solutions.
    - Sample quote: “Hearing perspectives from healthcare professionals and sociologists gave us ideas we wouldn’t have considered otherwise. It made our designs much stronger.”

2. Improved Communication and Understanding: Teams emphasized the importance of learning to communicate effectively across disciplines.
    - Sample quote: “It was challenging at first to explain technical concepts to non-engineers, but by the end, we found a common language that worked for everyone.”

3. Holistic Approach to Design: Students recognized the value of integrating technical, social, and cultural considerations into their solutions.

- Sample quote: “Working with advocates helped us focus on user needs beyond the technical aspects, making our design more meaningful.”

The quantitative and qualitative results underscore the effectiveness of multidisciplinary collaboration in fostering innovation and inclusivity. The higher collaboration scores among multidisciplinary teams reflect the positive impact of diverse perspectives, while the qualitative feedback highlights the growth in communication skills and holistic problem-solving. These findings emphasize the importance of integrating multidisciplinary teamwork into engineering education to prepare students for addressing complex, real-world challenges.

4. Innovative Design Outcome

The INCLUDE Framework emphasized the development of innovative, user-centered solutions tailored to the needs of individuals with intellectual disabilities. Through iterative prototyping and participatory evaluation, students created designs that balanced technical feasibility with inclusivity and real-world impact.

The usability and satisfaction of student-developed solutions were evaluated using feedback from end users and disability advocates. Results demonstrated consistently high ratings across projects:

- Average usability rating: 4.7 ± 0.2
- Average satisfaction rating: 4.6 ± 0.3
- Types of solutions developed included:
  - Assistive communication devices (e.g., speech-to-text tablets).
  - Cognitive training apps (e.g., memory games for individuals with intellectual disabilities).
  - Inclusive educational tools (e.g., learning kits for schools).

Iterative design cycles led to significant improvements in usability scores, with average usability increasing by 35% from the initial prototype to the final design.

Qualitative feedback from users and disability advocates highlighted the practicality and inclusivity of the designs. Key themes included:

1. Alignment with User Needs: Stakeholders appreciated the thoughtful integration of cognitive and social considerations into the designs.
   - Sample quote: “The app was intuitive and engaging for our users, and it showed clear consideration of their cognitive abilities.”

2. Iterative Refinement: Teams incorporated user feedback effectively, resulting in significant design improvements.
   - Sample quote: “The second version of the communication device addressed all the challenges we faced with the first. It’s much more user-friendly now.”

3. Potential for Real-World Impact: Many designs were praised for their practicality and potential scalability.
    - Sample quote: “This educational tool could be a game-changer for schools looking to better include students with intellectual disabilities.”

The results demonstrate the effectiveness of the INCLUDE Framework in fostering innovative, impactful solutions. High usability and satisfaction ratings, combined with positive feedback from stakeholders, underscore the value of user-centered design and iterative refinement. These findings highlight the potential of inclusive design education to produce practical and scalable solutions that address real-world challenges while fostering a deeper understanding of user needs among future engineers.

4. Effectiveness of Assessment Tools

The INCLUDE Framework incorporated innovative assessment tools to evaluate both technical and social dimensions of student projects. These tools ensured a holistic evaluation of project outcomes, capturing collaboration, empathy, user satisfaction, and technical feasibility.

Quantitative metrics demonstrated strong correlations between the use of assessment tools and project success:

- Collaboration scores, empathy development surveys, and user satisfaction ratings all showed significant correlations with project quality (Pearson’s $r > 0.8$).
- Participatory evaluation sessions yielded an average satisfaction score of 4.6 ± 0.3, reflecting the relevance and inclusivity of the designs.
- Empathy mapping exercises improved usability by an average of 35%, demonstrating the iterative refinement of designs based on user feedback.

Feedback from students and stakeholders highlighted the value of the assessment tools in guiding the design process. Key insights included:

1. Clarity in Identifying User Needs: Students found empathy mapping frameworks particularly helpful in understanding and addressing the challenges faced by end users.
    - Sample quote: “Using empathy maps gave us a structured way to visualize the needs of users, which improved our designs significantly.”

2. Enhanced Collaboration Dynamics: Structured co-design workshops facilitated real-time feedback, fostering a deeper connection between students and stakeholders.
    - Sample quote: “The workshops were invaluable. Hearing directly from users helped us refine our prototypes in ways we wouldn’t have thought of on our own.”

3. Focus on Holistic Metrics: Participatory evaluation models ensured that both technical and social impacts were considered, leading to more comprehensive solutions.

- Sample quote: “The assessment tools made us think about inclusivity and usability, not just technical performance. That shift changed how we approached our designs.”

Summary of Findings

The results validate the effectiveness of the INCLUDE Framework’s assessment tools in capturing the multifaceted outcomes of inclusive design projects. The combination of quantitative metrics and qualitative feedback highlights the transformative role of empathy mapping, participatory evaluations, and co-design workshops in producing impactful, user-centered solutions. These findings underscore the importance of integrating innovative assessment methods into engineering education to prepare students for real-world challenges with both technical rigor and social responsibility.

While the INCLUDE Framework demonstrated significant success in enhancing engineering education and fostering inclusive design, certain challenges were identified. These areas for improvement provide valuable insights for refining the framework and addressing potential barriers to its broader implementation.

Quantitative data revealed patterns indicating logistical and engagement challenges:

- Advocate engagement over time: User participation decreased by approximately 20% in longer project timelines (e.g., exceeding 8 weeks), highlighting the difficulty in sustaining advocate involvement.
- Variability in collaboration scores: Collaboration metrics showed higher variability in multidisciplinary teams, with standard deviations of 0.3 to 0.5, suggesting that team dynamics were occasionally uneven.

Thematic analysis of reflection journals, observational notes, and feedback sessions identified recurring challenges:

1. Sustaining Advocate Engagement: Disability advocates cited time constraints and logistical barriers as reasons for decreased involvement during extended project cycles.
    - Sample quote: “I wanted to continue contributing, but the timeline didn’t align with my other commitments.”

2. Inconsistent Team Dynamics: While multidisciplinary teams often excelled, some struggled with balancing diverse perspectives, leading to occasional miscommunication and delays.
    - Sample quote: “It was difficult at times to find common ground when team members approached problems from vastly different angles.”

3. Resource Constraints: Limited availability of tools or expertise in certain areas, such as advanced prototyping methods, hindered the implementation of some design ideas.

- Sample quote: “We had great ideas, but without access to specific resources, we couldn’t fully realize them.”

4. Scalability Concerns: Students and faculty raised concerns about scaling the framework for larger cohorts while maintaining its focus on individual user needs.
    - Sample quote: “The process was impactful, but I wonder how feasible it would be to replicate this experience with a much larger group.”

The challenges identified in the INCLUDE Framework highlight critical areas for refinement, including improved strategies for advocate engagement, enhanced team-building activities, expanded access to resources, and considerations for scalability. These findings emphasize the need for flexible collaboration models, structured team management, and additional institutional support to ensure sustained success in future iterations. Addressing these challenges will strengthen the framework’s impact and broaden its applicability in engineering education.

Analysis and Discussion

Empathy Development

The results highlight a significant improvement in empathy scores among students, reflecting the transformative potential of immersive and reflective learning experiences. The observed increase from a mean of 3.2 to 4.6 aligns with prior research emphasizing the role of experiential learning in fostering empathy within engineering education [17]. Activities such as sensory simulations and direct user engagement provided students with a unique perspective on the cognitive and social challenges faced by individuals with intellectual disabilities. This aligns with studies that show empathy-focused instruction improves the alignment of engineering designs with user needs [18].

Qualitative findings further underscored the impact of these activities, with themes such as heightened user awareness, a shift in design perspectives, and a commitment to inclusivity. Notably, students reported feeling more connected to the real-world implications of their designs, echoing the sentiments of Hess and Fila (2016), who demonstrated that empathy cultivation enhances design thinking and problem-solving capabilities in engineering students [19]. These findings validate the INCLUDE Framework's emphasis on empathy-driven learning as a cornerstone for developing socially responsible engineers.

Collaboration Metrics

The enhanced collaboration metrics in multidisciplinary teams emphasize the value of diverse perspectives in fostering innovation. The significant difference in scores between multidisciplinary teams (4.5 ± 0.3) and single-discipline teams (3.8 ± 0.5) underscores the effectiveness of cross-functional collaboration. These findings are consistent with Schlott’s (2024) analysis, which links functional diversity in teams to increased creativity and innovative performance [20].

Qualitative themes, including improved communication and a holistic approach to design, demonstrate how multidisciplinary teams navigated the complexities of intellectual disability-focused projects. However, challenges such as initial communication barriers highlight the need for structured frameworks to facilitate inter-disciplinary collaboration. The success of these teams validates the INCLUDE Framework's integration of healthcare professionals, sociologists, and disability advocates, ensuring holistic and user-centered solutions.

Innovative Design Outcomes

The high usability (4.7 ± 0.2) and satisfaction ratings (4.6 ± 0.3) of student projects reflect the success of the iterative design process embedded in the INCLUDE Framework. This aligns with existing literature suggesting that participatory evaluation significantly improves the inclusivity and practicality of engineering solutions [5]. Projects such as assistive communication devices and cognitive training apps highlight the potential for real-world impact, emphasizing that inclusive design is not only feasible but scalable.

The iterative refinement of prototypes based on user feedback improved usability by 35%, showcasing the critical role of participatory evaluation in user-centered design. This finding resonates with studies by Yeung and Ng (2024), who demonstrated that empathy mapping and direct user involvement result in more intuitive and accessible designs [21]. The consistent feedback about the designs' alignment with user needs further illustrates the framework's effectiveness in bridging technical and social dimensions.

Effectiveness of Assessment Tools

The INCLUDE Framework's assessment tools demonstrated strong correlations ($r > 0.8$) between empathy, collaboration, and project success, validating their utility in holistic evaluations. By integrating metrics such as empathy mapping, user satisfaction, and participatory feedback, the framework ensures comprehensive assessment beyond technical feasibility.

Participatory evaluation models, which recorded satisfaction scores of 4.6 ± 0.3, empowered disability advocates to provide actionable insights. This aligns with findings by Walther et al. (2016), which emphasize that inclusive assessments not only evaluate outcomes but also enhance learning by guiding iterative improvement [22]. The tools' ability to connect technical and social impacts underscores the importance of multidimensional evaluation frameworks in engineering education.

Challenges and Areas for Improvement

While the INCLUDE Framework demonstrated significant success, challenges such as sustaining advocate engagement and addressing resource constraints warrant attention. The 20% decrease in user participation over extended timelines highlights the need for flexible collaboration models that accommodate stakeholder schedules. This echoes Millen et al. (2011), who identified time constraints as a common barrier in participatory design [23].

The variability in collaboration metrics (SD = 0.3 to 0.5) suggests that some teams struggled to balance interdisciplinary dynamics. Addressing this requires enhanced training in

communication and conflict resolution to strengthen team cohesion. Additionally, the scalability concerns raised by students and faculty emphasize the need for institutional support in expanding the framework for larger cohorts without compromising its focus on individual user needs.

Connecting Findings to Broader Objectives

The findings of this study align with the manuscript's overarching goal of bridging technical expertise and social responsibility in engineering education. By integrating empathy-driven learning, multidisciplinary collaboration, and innovative assessment tools, the INCLUDE Framework addresses systemic gaps in the representation of intellectual disabilities in engineering design. This transformative approach prepares engineers not only to solve technical problems but also to tackle societal challenges with inclusivity and equity.

Future iterations of the framework should explore longitudinal studies to assess sustained impacts on student competencies and professional practices. Additionally, integrating emerging technologies such as virtual and augmented reality for empathy development could address logistical challenges while enhancing immersive learning experiences. Expanding collaborations to include policymakers and educators could further enrich the framework’s multidisciplinary approach, fostering broader societal impact.

Conclusion

The INCLUDE Framework transforms engineering education by integrating multidisciplinary collaboration, empathy-driven learning, and innovative assessment tools, equipping students to design inclusive, impactful solutions for individuals with intellectual disabilities. It emphasizes equity by addressing cognitive, social, and technical challenges often overlooked in traditional curricula.

While successful, challenges like sustaining stakeholder engagement and scaling require ongoing refinement. Future efforts should focus on leveraging emerging technologies and expanding partnerships to maximize impact. By embedding inclusivity into education, this framework prepares engineers to create transformative solutions that empower diverse communities.

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