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BOARD # 254: IUSE: A design thinking approach to fostering engineering students' empathy in smart manufacturing education

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Abstract

The rapid evolution of advanced manufacturing systems requires a workforce adept in solving the problem with an understanding of the impact of their solution on others. To address this critical need, this project aimed to equip students with abilities to develop empathy while solving authentic problems. A quasi-experimental study that integrated design thinking as an intervention was performed in a college-level engineering course. Control group students attended traditional curricular, while experimental group students engaged in an iterative design thinking process including building empathy, defining the problem, performing ideation, and creating prototypes and conducting evaluation. Students' cognitive empathy was measured by Interpersonal Reactivity Index before and after the course. Statistical analysis confirmed experimental group students developed a significantly higher level of cognitive empathy in solving engineering problems than those in the control group. The findings of this project demonstrated the potential of integrating design thinking into engineering education to improve students' understanding of advanced manufacturing and developing critical soft skills such as empathy.

Introduction

The rapidly evolving smart manufacturing systems lead to an increasing demand for skilled engineers who can drive innovation and shape the future of the industry. In the United States, the Bureau of Labor Statistics (2021) projects a 25% growth rate for engineers by 2031, significantly outpacing other professions. Therefore, preparing the next generation of engineers with competence of solving real-world smart manufacturing problems becomes increasingly critical.

A key metric for assessing the success of smart manufacturing systems is their ability to address human needs (Wang et al., 2022). Fostering prospective engineers' empathetic understanding of users' needs is essential for them to develop human-centered solutions (Tang et al., 2021). Empathy in this context refers to the ability to understand and share the feelings of others, which is a crucial skill for engineers who design solutions that directly impact people's lives (Casale et al., 2018). Traditional views of empathy distinguish between cognitive empathy, which involves understanding another person's perspective, and emotional empathy, which involves sharing the emotional experience of others (Casale et al., 2018; Cuff et al., 2016). Research has shown that empathy plays a vital role in college students' academic success and social development (MacCann et al., 2020; Pang et al., 2022; Smith et al., 2020). However, studies indicate that students' empathy skills often decline over time, with many struggling to fully comprehend a problem from others' perspective (Konrath et al., 2011; Lucas-Molina et al., 2024).

One potential way to cultivate empathy in future engineers is by providing opportunities for them to engage with design thinking, a human-centered problem-solving approach (Gumina & Tang, 2021; Li et al., 2019). Design thinking encourages students to approach challenges with a focus on understanding the user's needs and developing solutions that prioritize those needs. However, it remains unclear whether design thinking effectively enhances cognitive empathy in students, especially in the context of engineering (Malge, 2017; Rajaram, 2023).

This research aimed to fill this gap by examining how design thinking can contribute to the development of cognitive empathy in engineering students. Using a quasi-experimental approach, the study measured changes in students' empathy levels to examine the impact of the design thinking process on their cognitive empathy. The findings of this research have the potential to inform the development of curricula that equip future engineers with the empathy skills needed to create human-centered solutions to address user needs.

Literature Review

Empathy

Prospectus engineers should develop empathy when solving real-world engineering problems. Empathy, or a sense of emotional awareness for others, has long been considered a deeply embedded, or fixed, characteristic, one all humans are born with (Lasley, 2017); however, today's college students report a significant decline in empathy abilities (Konrath et al., 2011; Lucas-Molina et al., 2024), as compared to their predecessors of the 1970s (Konrath et al., 2011). There is a consensus that empathy encompasses a comprehension of other people's experience (cognitive empathy) as well as the ability to vicariously experience the emotional experience of others (affective empathy) (Casale et al., 2018; Cuff et al., 2016). A distinction between self and other is maintained and needs to be addressed in the definitions. In what follows, cognitive empathy will be understood as the ability to construct a working model of the emotional states of others, and affective empathy will be understood as the ability to be sensitive to and vicariously experience the feelings of others (Casale et al., 2018; Lucas-Molina et al., 2024; Reniers et al., 2011). Both cognitive empathy and affective empathy can exist individually; however, it is the handling and placement of cognitive elements that produces the affective elements (Cuff et al., 2016; Lucas-Molina et al., 2024).

Design Thinking

Design thinking has been adopted in the manufacturing industry to craft human-centric technical solutions (Henriksen et al., 2017) as a systematic method for technical design that progresses through five iterative phases, including empathy, definition, ideation, prototyping, and testing (Tang et al., 2021). The process begins with empathy, where students develop an understanding of their customers and the context to ensure their designs align with human needs (Yu et al., 2019). In the definition phase, students articulate a clear problem statement, which serves as a foundation for ideation (Gumina & Tang, 2021). In the ideation phase, students collaboratively generate and evaluate potential solutions and then select a feasible option that resolves the problem and meets human needs (Li et al., 2019; Wu et al., 2019). This leads to prototyping, where students create tangible representations of their solutions and anticipated outcomes (Tsai & Wang, 2021). Finally, an iterative cycle of testing is conducted to assess the prototype's effectiveness and refine it based on feedback (Gumina & Tang, 2021; Tsai & Wang, 2021).

As a core component of design thinking, cognitive and affective empathy are integrated to ensure that designers approach problems from the perspective of their intended users (Cook &

Bush, 2018; Lin et al., 2020). Additionally, design thinking fosters inclusivity by allowing all stakeholders, regardless of their roles, to actively engage in various stages of the design process (Retna, 2016; Wu et al., 2019).

Methodology

Participants and settings

The study was conducted at a public university in the Southeastern United States. A quasi-experimental design was employed to examine the impact of a design thinking approach on students' empathy skills within engineering courses. Prior to participant recruitment, the study received approval from the Institutional Review Board. The courses selected for this study focused on designing Internet of Things applications, utilizing design knowledge and skills. Two sections of this course, both taught by the same instructor, were included in the study and randomly assigned to two conditions, the experimental group attending the intervention and the control group taking the traditional engineering curriculum. An independent samples t-test was conducted to ensure there were no pre-existing differences in empathy skills or knowledge between the groups. In total, 43 students voluntarily participated in the study, 21 in the experimental group and 22 in the control group.

Intervention

The intervention of this study was to integrate the design thinking approach. This design thinking experience started with an informational session with liaisons who expressed their needs and expectations, shared their real-life experience about engineering positions, and discussed their professional expectation about qualified job candidates. This informational session allowed engineering students to understand the custom needs in an authentic setting and align their own project goals with professional expectation. At the beginning of the semester, the class took a group site visit to learn about the customers' needs. Then students formed a team of three to four and attend to a series of design thinking activities, including empathy, definition, ideation, prototyping, and testing (Gumina & Tang, 2021; Tang et al., 2021). Particularly, the outcome included a design briefing that recorded their design experience and a prototype of the smart manufacturing applications.

Data Collection and Analysis

The Interpersonal Reactivity Index (Davis, 1980) was used to assess students' levels of empathy before and after taking the course. Particularly for this project, cognitive empathy was assessed by two subscales, including empathic concern and perspective taking. Cronbach's alpha was calculated to confirm the internal consistency for pretest (.857) and posttests (.829) was acceptable. Descriptive statistics were conducted. Then analysis of covariance (ANCOVA) was performed to investigate the difference in students' cognitive empathy between the two groups, with pre-test empathy scores as the covariate.

Results

Experimental group exhibited an average post-test score of 5.09 with a standard deviation of 1.23 with a noticeable improvement from their pre-test mean score of 4.60 with a standard deviation of 1.18. The control group showed a lower post-test average of 4.26 with a standard deviation of 1.38, while decreased from their pre-test average of 4.37 with a standard deviation of 1.14. The ANCOVA result underscored the evidence of improved student empathy as the group differences in post-test cognitive empathy scores were statistically significant, with an $F(1, 40) = 39.80$, $p < .05$. The effect size gauged by eta squared ($\eta 2$) value showed that the intervention accounted for approximately 49.9% of the variance in post-test cognitive empathy scores between the groups, showing a large effect size.

Findings

The findings of this project underscore the significance of integrating design thinking into engineering education. This model enhanced students' understanding of smart manufacturing and fostered their empathy which is an essential soft skill for engineering. This model also provides a replicable framework for preparing future engineers to navigate the complexities of modern manufacturing systems by equipping them with technical expertise and soft skills needed to drive innovation and create solutions that prioritize user needs and societal impact.

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References

Bureau of Labor Statistics. (2021). *Employment in STEM occupations: U.S. Bureau of Labor Statistics*. https://www.bls.gov/emp/tables/stem-employment.htm

Casale, C., Thomas, C. A., & Simmons, T. M. (2018). Developing empathetic learners. *Journal of Thought*, *52*(3–4), 3–18.

Cook, K. L., & Bush, S. B. (2018). Design thinking in integrated STEAM learning: Surveying the landscape and exploring exemplars in elementary grades. *School Science and Mathematics*, *118*(3–4), 93–103.

Cuff, B. M., Brown, S. J., Taylor, L., & Howat, D. J. (2016). Empathy: A review of the concept. *Emotion Review*, *8*(2), 144–153.

Davis, M. (1980). A multidimensional approach to individual differences in empathy. *Catalog of Selected Documents in Psychology*, *10*, 85–96.

Gumina, S., & Tang, H. (2021, October). *Inspiring Student Creativity: Collaboration on a Network Design Using IoT Project*. The 22nd ACM Annual Conference on Information Technology Education (SIGITE 2021), Snowbird Resort, Utah.

Henriksen, D., Richardson, C., & Mehta, R. (2017). Design thinking: A creative approach to educational problems of practice. *Thinking Skills and Creativity*, *26*, 140–153.

Konrath, S. H., O'Brien, E. H., & Hsing, C. (2011). Changes in Dispositional Empathy in American College Students Over Time: A Meta-Analysis. *Personality and Social Psychology Review*, *15*(2), 180–198. https://doi.org/10.1177/1088868310377395

Lasley, J. (2017). Developing Empathic Communication Skills Through Service Learning: A Qualitative Case Study. *Radiation Therapist*, *26*(2).

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). Design and Design Thinking in STEM Education. *Journal for STEM Education Research*, *2*(2), 93–104. https://doi.org/10.1007/s41979-019-00020-z

Lin, L., Shadiev, R., Hwang, W.-Y., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. *Thinking Skills and Creativity*, *36*, 100646.

Lucas-Molina, B., Giménez-Dasí, M., Quintanilla, L., & Sarmento-Henrique, R. (2024). Spanish Validation of the Two-Factor Interpersonal Reactivity Index: Evidence for the Relationship Between Empathy, Social Competence, and Emotion Regulation. *Early Education and Development*, *35*(3), 615–627. https://doi.org/10.1080/10409289.2023.2187189

MacCann, C., Jiang, Y., Brown, L. E. R., Double, K. S., Bucich, M., & Minbashian, A. (2020). Emotional intelligence predicts academic performance: A meta-analysis. *Psychological Bulletin*, *146*(2), 150–186. https://doi.org/10.1037/bul0000219

Malge, A. M. (2017). Designer's Cognitive Empathy and Emotional Empathy Measurement, a Need for Comprehensive Understanding of User. *2017 International Conference on Transforming Engineering Education (ICTEE)*, 1–4. https://doi.org/10.1109/ICTEED.2017.8586030

Pang, Y., Song, C., & Ma, C. (2022). Effect of Different Types of Empathy on Prosocial Behavior: Gratitude as Mediator. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.768827

Rajaram, K. (2023). Social-Psychological Intervention: Development of Cognitive Empathy. In K. Rajaram (Ed.), *Learning Intelligence: Innovative and Digital Transformative Learning Strategies: Cultural and Social Engineering Perspectives* (pp. 119–146). Springer Nature. https://doi.org/10.1007/978-981-19-9201-8_3

Reniers, R. L. E. P., Corcoran, R., Drake, R., Shryane, N. M., & Völlm, B. A. (2011). The QCAE: A Questionnaire of Cognitive and Affective Empathy. *Journal of Personality Assessment*, *93*(1), 84–95. https://doi.org/10.1080/00223891.2010.528484

Retna, K. S. (2016). Thinking about "design thinking": A study of teacher experiences. *Asia Pacific Journal of Education*, *36*(sup1), 5–19.

Smith, K. E., Norman, G. J., & Decety, J. (2020). Medical students' empathy positively predicts charitable donation behavior. *The Journal of Positive Psychology*, *15*(6), 734–742. https://doi.org/10.1080/17439760.2019.1651889

Tang, H., Gumina, S., & Wang, S. (2021). Building design thinking into an authentic Internet of Things instruction. *2021 Tenth International Conference of Educational Innovation through Technology (EITT)*, 24–27. https://doi.org/10.1109/EITT53287.2021.00014

Tsai, M.-J., & Wang, C.-Y. (2021). Assessing young students' design thinking disposition and its relationship with computer programming self-efficacy. *Journal of Educational Computing Research*, *59*(3), 410–428.

Wang, B., Zheng, P., Yin, Y., Shih, A., & Wang, L. (2022). Toward human-centric smart manufacturing: A human-cyber-physical systems (HCPS) perspective. *Journal of Manufacturing Systems*, *63*, 471–490. https://doi.org/10.1016/j.jmsy.2022.05.005

Wu, B., Hu, Y., & Wang, M. (2019). Scaffolding design thinking in online STEM preservice teacher training. *British Journal of Educational Technology*, *50*(5), 2271–2287. https://doi.org/10.1111/bjet.12873

Yu, K.-C., Wu, P.-H., & Fan, S.-C. (2019). Structural Relationships among High School Students' Scientific Knowledge, Critical Thinking, Engineering Design Process, and Design Product. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-019-10007-2