Strengthening the Future Manufacturing Workforce: Exploring First-Year Engineering Students' Awareness and Motivation toward Manufacturing Careers

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Abstract

Strengthening the US manufacturing competitiveness has been an issue which is widely agreed upon by the national leadership across most states. With international investments in manufacturing in the US, it is imperative that there will be a growing need for a skilled workforce in the manufacturing sector. However, the concepts of manufacturing, like production systems (e.g., mass production) and modern manufacturing ideas (e.g., 3D printing), as well as the associated career paths, are mostly introduced in engineering education in the later phases of a conventional degree program; such a delayed introduction and exposure of manufacturing concepts to engineering students can deter them from pursuing a career in manufacturing.

Early exposure to content in manufacturing can support students' awareness of and motivation towards a career in manufacturing. To design effective exposure opportunities related to manufacturing, understanding first-year engineering students' perceptions and awareness of manufacturing would be helpful. Therefore, this study has two main objectives: O1) to understand the initial perceptions and motivations of first-year engineering students on a career in manufacturing, and O2) to understand the impact of a manufacturing-specific educational intervention, by comparing students' perceptions and their ability to relate manufacturing concepts to the intended major, before and after the exposure to content in manufacturing.

To address these research objectives, the research team conducted a pre- and post-survey study where the data collection instrument was distributed to around 325 students in the first-year engineering course. In the first phase survey, the students' initial perceptions, understanding, and motivations to pursue a career in manufacturing were queried, and it was followed by an introductory exposure to content on manufacturing. The content was centered around the ideas of mass production, 3-D printing using metals, and data analysis. In the second phase, students' perceptions and ability to relate their intended major to manufacturing were surveyed, which was conducted after the manufacturing content was presented to the students. The information on initial motivations and the change in a student's perceptions and ability to relate manufacturing and their major choice could help in better preparing both the instructors for developing future educational content on manufacturing and the manufacturing sector recruitment officials to engage with the future workforce. The findings of this study will underscore the need for introductory content for first-year engineering students and pre-college students.

Introduction

The manufacturing sector plays a critical role in the economic health of the United States, contributing significantly to job creation, technological innovation, and global competitiveness [1]. However, the industry faces considerable challenges, particularly concerning workforce development. The necessity for a skilled workforce in manufacturing is underscored by numerous studies highlighting the impending skills gap as the existing workforce ages and new technologies emerge [2, 3]. As the demand for advanced manufacturing techniques, such as automation and additive manufacturing, grows, the education system must adapt to prepare students for these evolving roles [4].

Manufacturing education is relegated to upper-level courses in engineering programs, limiting students' exposure to critical concepts such as production systems, 3D printing, and data analytics until they are well into their studies [5-7]. This delayed introduction can lead to a lack of awareness of the diverse career opportunities available within the manufacturing sector [8]. Early exposure to manufacturing concepts is crucial for cultivating interest and awareness among engineering students. Research indicates that many students may lose motivation in manufacturing careers when exposed to the field too late in their academic journey [9]. By introducing manufacturing principles at the start of engineering education, institutions may be able to foster a pipeline of skilled graduates ready to meet industry demands [10]. Programs that integrate manufacturing content into the first-year curriculum have shown promise in increasing student engagement and motivation toward careers in this sector [11].

Students often enter their programs with preconceived notions about engineering careers, which may not encompass the breadth of roles in manufacturing [12]. Students' self-motivation, social persuasion, self-efficacy, personal utility, and positive experiences are motivational aspects that drive a student's career choice [13]. Knowing the motivation factors is vital for modifying the intervention for sensitization of students to better relate the content for better connectivity to their studies. This perceived relevance may yield prolonged actualized interest in the students. Therefore, understanding the motivational factors that influence students' career choices in manufacturing is essential.

Prior research has identified several key motivators for career pursuit in manufacturing, including job stability, salary potential, prior experiences and the opportunity to work with cutting-edge technology [14, 15]. While these studies have specifically focused on motivation for career choice for engineers and first-year engineering students in general, exploration of specific motivational factors for selecting manufacturing as a career path is missing. By identifying what drives students' interests in manufacturing, educators can better tailor their curricula and outreach efforts to align with student motivations [16]. This alignment of students' motivation can be observed by understanding perceived relevance of manufacturing to their major, because relevance is a component for situational interest [17]. Situational interest is defined as a short-term psychological state of focused attention which is caused due to a situation or a context [18]. Based on the understanding of students' situational interest through perceived relevance, educators can decide the best pedagogical approach for such interventions.

To address the gap in knowledge regarding first-year engineering students' perceptions of manufacturing careers, this study adopts the following research questions: RQ1.1) What are first-year engineering students' initial perceptions of a career in manufacturing? RQ1.2) What motivators do students identify as supporting consideration of a career in manufacturing? RQ2.1) How does the manufacturing content exposure to manufacturing affect students' perceptions of a manufacturing career? RQ2.2) How do the students connect their intended major to manufacturing after exposure to manufacturing content?

This study utilizes a pre- and post-survey approach to gather data from approximately 325 students enrolled in an introductory engineering course, "Foundations of Engineering." The first phase of the survey aims to capture students' initial perceptions and motivations regarding manufacturing careers. Following this, an introductory session covering essential manufacturing concepts, including mass production, 3D printing, and data analyses is conducted. The second phase of the survey evaluates how this exposure influences students' perceptions and their ability to relate their intended major to manufacturing.

By understanding students' initial perceptions and the impact of an intervention on manufacturing content, educators can design curricula that better prepare future engineers for careers in manufacturing. Furthermore, the findings can assist the tailored recruitment of officials in the manufacturing sector as an additional intervention by highlighting the aspects of manufacturing careers that resonate most with students. By embedding manufacturing concepts early in engineering education, institutions may be able to play a critical role in addressing workforce challenges and ensuring the long-term viability of the manufacturing sector in the U.S.

Background

Prior research highlights that first-year engineering students' motivations and career expectations are shaped by a complex interplay of personal interests, perceived job fit, compensation, social influences, and classroom climate [14, 16]. Studies have shown that students' sense of identity and belonging in engineering strongly influences their persistence and career aspirations, while course design and instructor support can either strengthen or weaken these motivations [19]. Classic work has examined why students choose specific fields, such as mechanical engineering, and broader surveys have explored engineering career motivations in general [15, 20]. At the same time, educational innovations such as flipped classrooms and hands-on manufacturing-focused courses have demonstrated strong engagement and skill acquisition in areas like CAD, additive manufacturing, and robotics [21].

Despite these advances, relatively little is known about how first-year students specifically perceive careers in manufacturing. Existing studies tend to focus on engineering careers broadly with lack of sectoral focus, leaving a gap in understanding students' expectations and perceptions of manufacturing as a professional pathway. Few studies directly measure how targeted course experiences, such as guest lectures or project-based labs, influence students' curiosity, perceptions of relevance to their intended majors, or willingness to consider manufacturing careers [21]. Moreover, while motivations like compensation and person-job fit are well documented, contemporary drivers such as mentorship, classroom exposure to "making," and societal impact narratives remain underexplored in the context of manufacturing [14, 16].

While motivation and interest are essential for continued engineering student engagement, it is essential to understand the perceived relevance of a subject, which serves as the initiator of the interest [22]. Relevance of course content is considered as a driver of situational interest [17]. Understanding the intervention's impact on perceived relevance can better help educators in altering the future interventions to make content more relatable to students.

Methods

Data Collection

This study was set up to understand perceptions of students and the interventional impacts of manufacturing contents on first-year engineering students. The sampling of students was done for engineering students who were enrolled in the first-year engineering "Foundations of Engineering" course at an R1 university. To answer the research questions around initial perceptions and the impact of intervention, the data collection was set up before and after the intervention for 325 students. QuestionPro served as the tool for data collection, which was a secure option offered by the institution. The pre-intervention survey was launched four days prior to the date of intervention till the opening session of the intervention. The post-intervention survey was shared after the completion of the intervention, which collected responses for ten days.

The intervention comprised of a guest lecture presentation, a manufactured sample demonstration, career opportunities, and quantitative data analysis around manufacturing. The topic of these portions was centered around "laser 3D metal printing" and "sample heat data analysis." The intervention started with an opening discussion on the role of manufacturing in students' lives and what kind of careers look like in manufacturing. The discussion was followed by the guest presentation on laser 3D metal printing as an example of innovation in manufacturing where the 3-D printed metal samples were shared among the students to observe the process and product quality. The latter part of the intervention was on heat data of the 3-D printing process of the samples to analyze the differences in sample based on different heat intensities. The heat data of the sample was shared with the students for analysis using MATLAB, where the students applied the concepts of central tendencies to learn more about different intensities of laser impacting the thermal activities of a metal sample.

The valid samples for pre- and post-intervention surveys were found to be 165 and 137, respectively, which comprised of adult respondents only. The quantitative survey instrument used in this study included Likert-scale items for measuring degrees of interest, curiosity, and perceived relevance, which were set from 0 to 4 in increasing degrees of the measured virtue. These questions included “How interested are you in pursuing a career in manufacturing?”, “To what extent does your preferred major relate to manufacturing processes?”, and “To what extent did the manufacturing content make you curious about a career in manufacturing?” The qualitative survey instruments were the open-ended questions on reasoning for interest, curiosity and perceived relevance. These open-ended questions included “Why are you interested or not interested in pursuing a career in manufacturing?”, “Which components of the manufacturing content in lectures motivated you in considering a career in manufacturing?”, and “Please discuss how your preferred major is related to manufacturing process. You may choose an object which is manufactured and the part of the manufacturing process that is related to your preferred major.” The research project was approved by the Institution Review Board.

Data Analysis

For the open-ended questions, the responses by the students were manually analyzed by inductive analysis [23]. The quantitative data analysis was focused on the descriptive statistics of the distributions and a paired t-test to compare means of perceived relevance before and after the intervention. The statistical analysis was performed using R-Studio.

To compare the perceived relevance, the research team only used responses from those who participated in both surveys. This yielded a 50-student sample for these inferential statistics, where the Likert-scale variables were set as continuous variables. The analysis of questions on students’ interest in manufacturing careers answered RQ1.1. The students’ responses to the motivators question answered RQ1.2. The descriptive analysis of post-intervention curiosity of students towards manufacturing as careers answers RQ2.1The students responses to relevance of the manufacturing career in their preferred major question offered insights on the impact of the manufacturing intervention which, answered RQ2.2.

Findings

The survey responses indicated a gap in their understanding of the manufacturing career and the associated career prospects. In this section, the research team presents the findings based on the research questions for this study.

Students' Background and Initial Perceptions of Manufacturing Careers

The first-year engineering student responses collected in the pre-lecture survey offered insights on whether they have any experience/exposure related to any manufacturing process, their rating of interest in manufacturing as a career path and the associated reason behind their interest or lack thereof. The research team shared the survey with 329 students, after which they observed 165 eligible responses and had further checked them for valid responses to the survey questions.

The fig. 01 presents the proportions within the valid responses to the question "do you have any prior experience/exposure related to any manufacturing process?" The total number of valid responses to this question is 163, where the missing responses were not counted for assessment. Out of 163 responding students, most of the first-year engineering students (73%) had no prior experience or exposure to any manufacturing process.

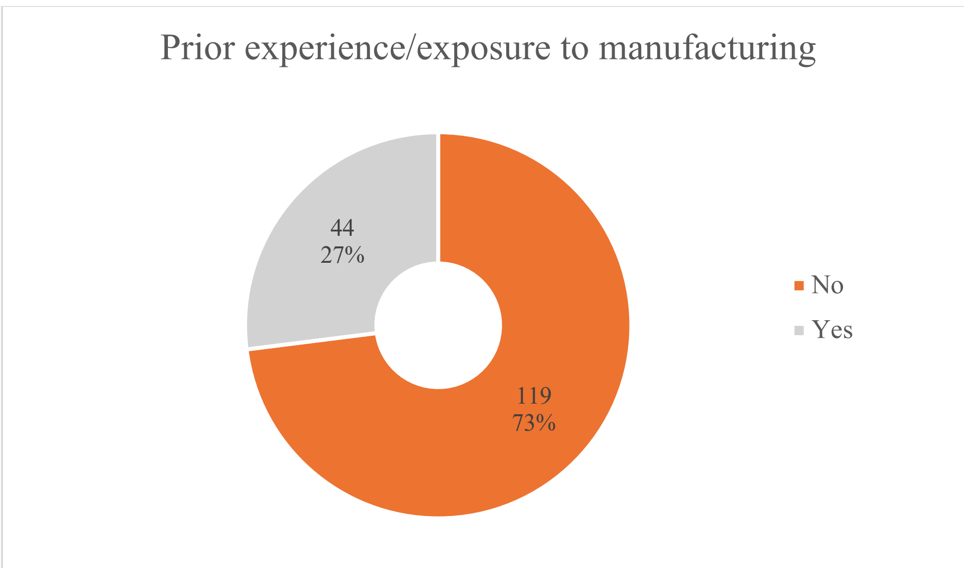

Figure 1. Distribution of first-year engineering students with prior manufacturing exposure/experience

To further explore the students' perceptions, the research team evaluated the students' degree of interest in manufacturing as a career. The fig. 02 presents a distribution of 145 valid responses for students' degrees of interest in manufacturing. The survey presented a distribution of students who have varied magnitudes of interest in manufacturing. It was found that a major portion of the students responding to the survey had a slight interest in manufacturing. This followed a lowering trend as observed in the figure 02 as the degree of interest increases from slight to moderate interest and so on. It was also observed that out of 145 respondents, only 16 students showed no interest in manufacturing.

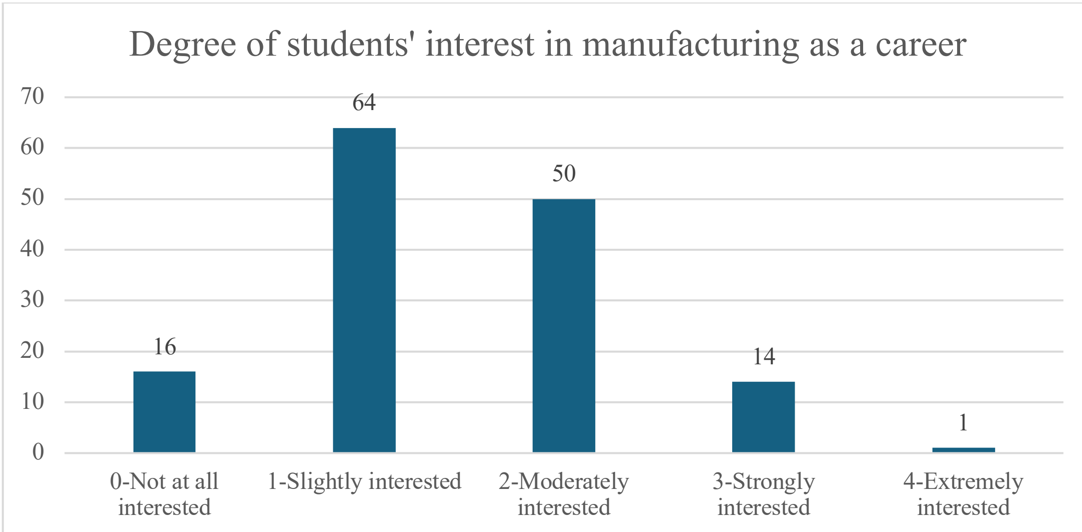

Figure 2. Distribution of the degree of interest in manufacturing career among students

The survey also asked for students' reasoning behind their perceived degree of interest or disinterest in the form of an open-ended question. The common themes that appeared for students exhibiting slight interest or higher, were the "interest in process", "career opportunities," and "alignment in major choice." An example of alignment and career opportunity as drivers of interest was *"I am moderately interested as manufacturing works with technology as a whole and has a lot of career advancement opportunities. Manufacturing is also high demand, leading to more job openings."* Some students had positive initial perceptions of manufacturing despite an understood lack of awareness of manufacturing. For example, a student said, *"Seems interesting from the surface level knowledge I have on the topic."* Six students who indicated a prior exposure had a positive degree of interest and attributed their experiences/exposure as the reason for their interest in manufacturing in responses like *"I took a dual enrollment precision machining class in 12th grade, got a basic machining certificate, and I think the concept of it is very interesting. Watching everything slowly come together felt very exciting."*

Another common theme that was observed among the student responses was a lack of awareness of manufacturing, where students indicated slight to moderate degrees of interest in manufacturing through statements like *"I am moderately interested but I don't know a lot about manufacturing as a whole. To be more specific, I don't know what positions or job requirements are involved with manufacturing."* The students who indicated lower degrees of interest (slightly interested or not at all interested) typically could not relate manufacturing to their career path. In these cases, students responded with showing interest in opportunities which were related to different majors through statements like *"My primary motivation for being involved in a specific type of engineering over a role in manufacturing is both salary and variety. Manufacturing jobs are the same and vary little day by day, whereas research or design-related areas have more variety. Additionally, experts in manufacturing often do not receive as high compensation."*

These outcomes indicate a limited awareness of first-year engineering students towards manufacturing as an industry and as a possible engineering career option for those who showed a non-zero degree of interest. The students who indicated that they were not at all interested, provided the reasoning of interest in other career direction and opportunities. This presents a case for having an introductory exposure to the first-year engineering students where they can be exposed to demonstrations of processes, discussions on career opportunities and applicability across multiple fields of engineering. This limited awareness and interest to manufacturing ties to an indifferent initial perception of manufacturing career pathways.

Students' Perceived Motivators

As discussed in the previous sections, the students' career choice motivation has been specifically explored for this study, and the factors found in the literature were given to students to select. Fig 03 indicates the number of students selecting a type of motivator that could drive their interest in a manufacturing career. The *Interest in Process* was the most selected motivator, which was indicated by 99 students. The motivators like *Compensation/Reward* (96 students), *Technical Exposure* (90 students), and *Perception of Person/Job Fit* (77 students) were indicated to be impactful by high numbers of students as motivators to pursue a career in manufacturing. Factors like *Family Influence* (20 students), *Societal Influences beyond Family* (26 students), and *Classroom Environment* (26 students) were impactful for a lesser number of students. The students were also allowed to share motivators other than the ones found in the literature within the multiple-choice options as "other:", but no valid responses were reported as motivators beyond the existing set.

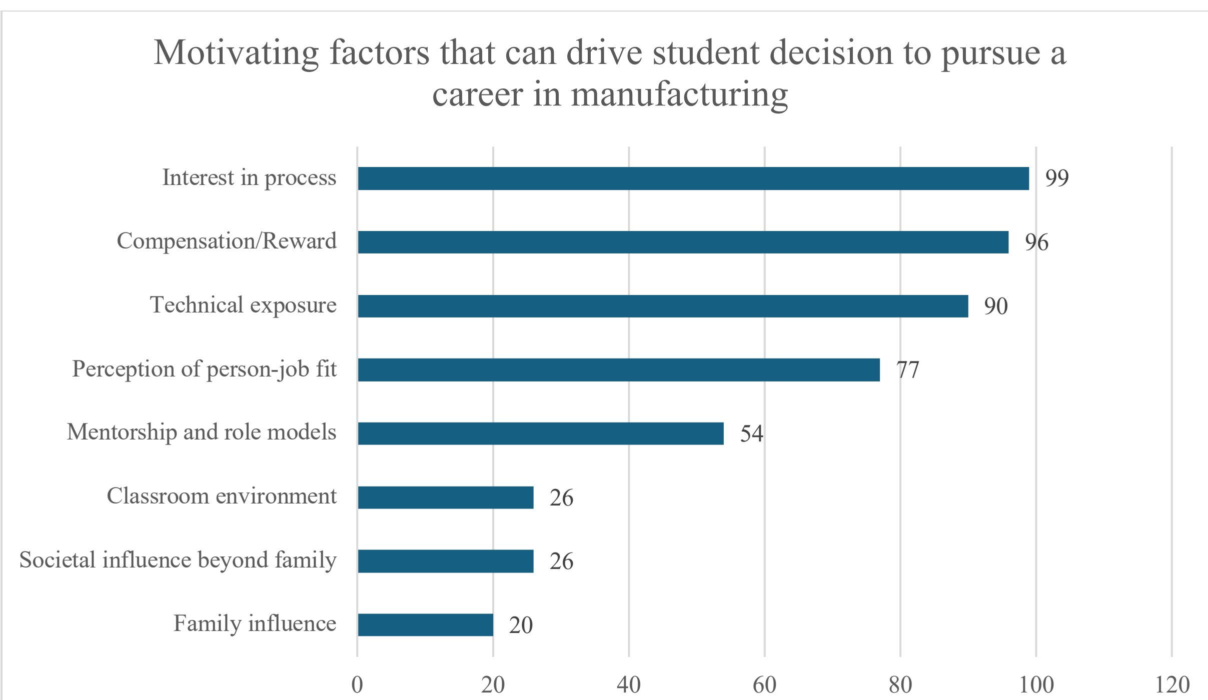

Figure 3. Distribution of students selecting different motivators in pursuing a career in manufacturing.

These results suggest that *interest in process*, *technical exposure*, *perception of person/job fit*, and the anticipated *compensation/reward* of a career path in manufacturing are more common motivators for first-year engineering students in potentially pursuing a career in manufacturing. The factors like family and other social influences and classroom environment were found to be impactful by relatively smaller number of students. Understanding the common motivators of students can further help instructors tailor future interventions for a better reception of manufacturing from students.

Post-Exposure Student Perceptions

The students were asked to share the extent to which the manufacturing module made them curious about careers in manufacturing after the delivery of manufacturing content and discussions related to associated job opportunities in their field. The students were asked to rate the degree of impact that the module made them curious about manufacturing on a scale ranging 0-4 where 0 signifies no impact on curiosity and 4 entails high impact on curiosity. The fig 04 presents the distribution of students' impacted degree of curiosity. The research team found 137 responses for this question and found that only 11 students among the respondents stated no curiosity towards a career in manufacturing as opposed to 126 students who showed some degree of curiosity. Many respondents indicated a moderate degree of curiosity towards manufacturing, as seen in the fig 04. The average degree of curiosity for the responding student sample came out to be 1.87.

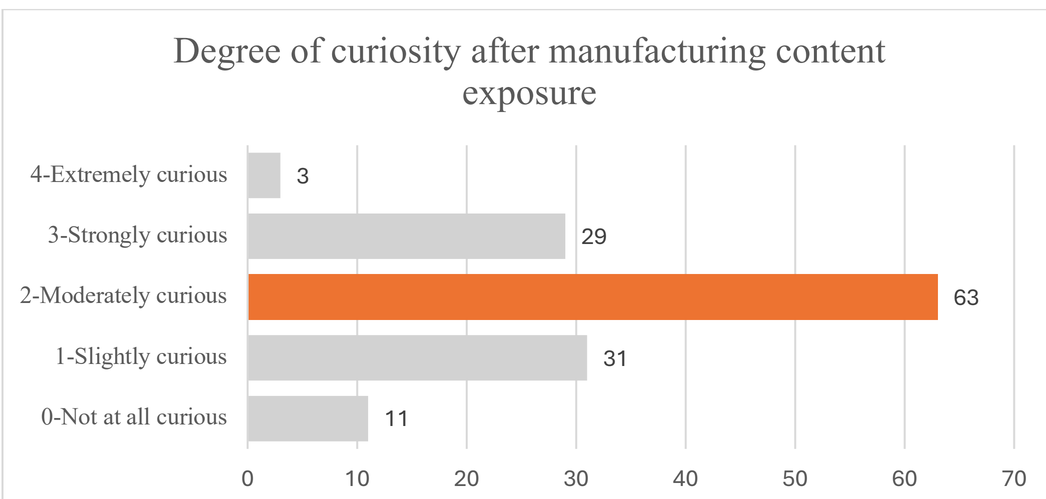

Figure 4. Distribution of impact on students' curiosity to consider a career in manufacturing

Around the same theme, the students were also asked about which components of the manufacturing content motivated them to consider a career in manufacturing as an open-ended question. The students' responses presented multiple themes around the manufacturing content and its relevant applications. The most frequently recurring themes were about the example process of metal-based 3-D printing, which was an example of the innovation introduced as a part of the content delivery. As quoted from a student's response: *"Something that did interest me in manufacturing was learning about the materials and how they are used in unique and specific* *ways. Like the Metal 3d printing, I'd never would thing to continuously add a thin layer of, essentially metal powder and heat the sections that would eventually create the intended piece."*

The other prominent points driving students' curiosity were the applications of manufacturing, the data analytics process involved in manufacturing, how manufacturing is associated with different fields of engineering, and possible job opportunities. A few students also indicated that their curiosity was also impacted due to the novelty of the processes described as a part of the content and how the content itself was delivered. While this was visible, the need for including more time for discussing manufacturing content and opportunities was also observed in students. An example of such is: *"The realization that the world of manufacturing is very diverse and there are many possibilities on how to make things. I said I was only slightly motivated, though, because I am still unsure of what specification and career path I want to pursue."*

These findings offer, in general, a positive degree of student perceptions towards a career in manufacturing after exposure to new content. From the collected data, it can be inferred that students feel a slight to moderate degree of curiosity towards pursuing manufacturing as a career path. This owes to the average value of the degree of curiosity as 1.87 on a scale of 0-4. This virtue of curiosity was scaffolded by the introduction of the types and applications of the processes, which have impacts on different fields of engineering and job opportunities.

Students' Perceived Relevance between Manufacturing and Preferred Major

To understand students' perceived relevance between their preferred major and manufacturing, the pre-lecture and post-lecture survey inquired into the degree to which a student relates the two, and how they form their perceived association. In the pre-lecture survey, the research team observed 165 valid responses to the question pertaining to the degree of perceived relevance. Fig 05 presents the distribution of students' perceived relevance of manufacturing before the intervention. A major fraction of students perceived manufacturing to be moderately (36.36%) and strongly (35.76%) relatable to their major.

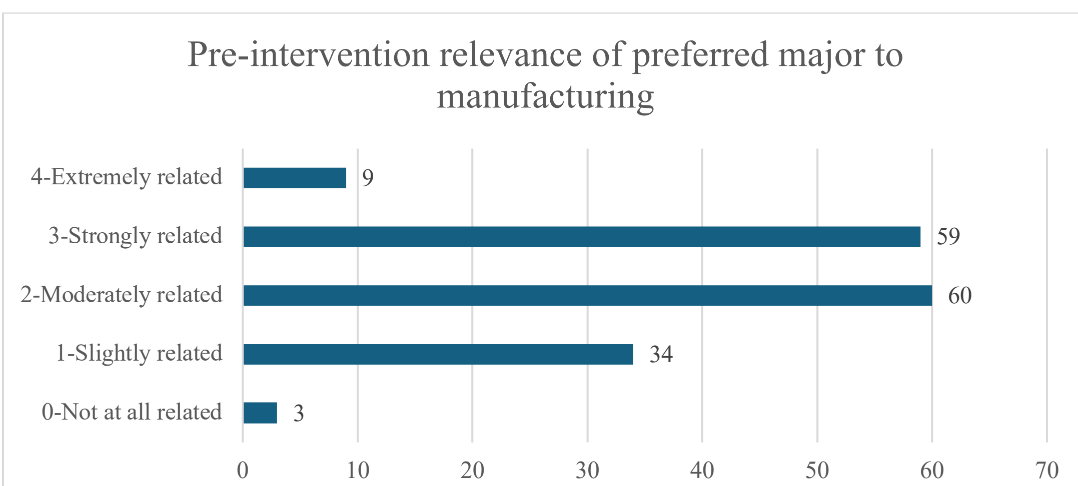

Figure 5. Distribution of students' perceived relevance between manufacturing and their major before the intervention

For further assessment of this pre-lecture perceived relevance, the research team observed the students' responses to the open-ended question on how they relate their preferred major and manufacturing. The students were found to relate the two widely on the themes of product design and the process of manufacturing itself. These themes were evidenced by 77 statements like *"My major is related to the manufacturing process in the way that my major tends to link to the design steps. Also, in the sense that most of the machinery required for the manufacturing process are also made by engineers of my major usually."* Another emergent theme was the idea around manufactured products serving as essentials for other engineering fields, which were identified in 32 statements like *"Computer Science is related to the manufacturing process because manufacturing engineers are responsible for creating the physical components of computer hardware."* Some less frequently emerging themes include automation, supply-chain, and logistics. These were collectively observed in 34 statements like *"My preferred major is primarily related to the manufacturing process from an analysis standpoint as Computer Science concepts are frequently used to analyze logistics and stats to optimize manufacturing processes and overhaul systems."*

The post-lecture survey yielded newer response to the same questions. A total of 131 valid responses were observed for students' degrees of perceived relevance between their preferred major and manufacturing. Fig 06 presents the distribution of students' degrees of perceived relevance with the responses indicating that students had moderate to strong perceived relevance between major and manufacturing. More than 41% of the responding students were able to moderately relate between the two. Only 3.05% of the students found no association between the two.

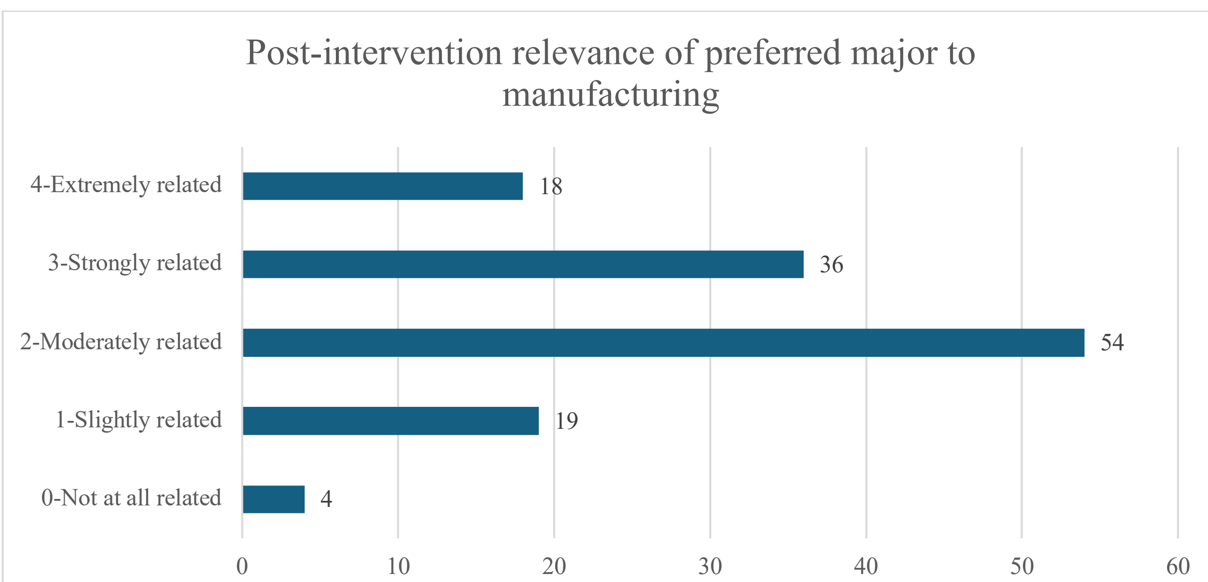

Figure 6. Distribution of students' perceived relevance between manufacturing and major after the intervention

The same survey also collected students' responses to how they relate their major and manufacturing. The open-ended responses indicated similar themes, which were observed in the pre-lecture survey, except for a few differently emergent themes as well. The themes like dependency of engineering fields on manufactured products was most frequently observed in students' responses. This theme was observed in 31 statements like *"Mechanical Engineering is involved in the development in mechanical parts. Manufacturing is critical in the creation and optimization of these parts. For example, in order for a mechanical engineer to design an engine, the cylinders and exhausts must be manufactured."*

The aspects of perceived relevance through design of products, processes, machinery, and facilities were also reflected in students' statements like *"Mechanical engineering is heavily involved in the manufacturing process. There is a lot of designing and prototyping in mechanical engineering. Mechanical engineering also designs a lot of heavy machinery that is used in the manufacturing process. Specifically, one object, that piques my interest in manufacturing is car frames. I would really enjoy changing and designing car frames for weight savings and aerodynamacy."* The newer themes included the relation of major to manufacturing through the examples of involved processes. The research team could find statements like *"For the test pieces shown by the guest speaker when talking about additive manufacturing/3d printing, those machines need to be programmed to process different models designed in software's and convert the contents into files that can be understood by a machine, this aspect is Computer Science related."*

To analyze the quantitative difference of the intervention, the responses of the students who participated in both pre and post lecture survey were further analyzed. The degrees of perceived relevance were identified as continuous variables by evaluating their corresponding quantitative values, which ranged from 0-4. Based on this, the research team conducted a paired t-test of perceived relevance values for the 50 students who responded to both surveys. The mean perceived relevance before intervention was found to be 2.41 while the same value after intervention came out to be 2.64. The analysis results indicated $t(50) = 2.368$, $p < 0.05$, and the 95% confidence interval for the mean difference as (0.036, 0.435), suggesting a significant increase in perceived relevance after the intervention.

Discussions

The findings highlight the status of first-year engineering students in terms of their perceptions and motivation towards manufacturing. Most students showed limited prior exposure to manufacturing. The research team also observed that the initial interest was slight-to-moderate in degree. While the open-ended responses present low awareness of engineering students towards manufacturing, this does not imply a lack of students' potential to consider manufacturing as a career path. This deficiency can be tackled by avoiding delayed exposure to concepts and opportunities around manufacturing.

The analysis of individual students' responses highlighted dominance of process-related interest, person-to-job fit, and compensation as motivators for them to consider a career in manufacturing while the contrasting finding was found for social/family influence as a motivator. Based on the inferences from the findings of motivators, the future interventions are recommended to highlight individual benefits to guide students towards manufacturing careers. While the structured presentation of manufacturing careers is essential, technical experience is also needed for students by the means of structured interventions.

These exposure-centric interventions i.e. the interventions that are designed for sensitizing, play a key role in generating curiosity among the students through basic information, exemplary processes, and opportunities related to the subject. Not only it clarifies the misconceptions about manufacturing as a low-paid and repetitive job, but it also helps students find some concepts that are related to their interests. This can set up the opportunity for students to undergo prolonged exposure, yielding actualized interest among students. The literature also suggest that prolonged exposure to situational interest can convert the same to an actualized interest [24]. This would result in creation of a workforce with actualized interest and thus regaining the strength of the manufacturing workforce.

The intervention stimulated the students' interests by making the content relatable to them, by helping them make associations between their preferred major in engineering and manufacturing. It was found that the degree of perceived relevance of students was significantly increased after the intervention, where students reflected on the demonstrated examples and hands-on data analysis activity as a way to relate their intended major to manufacturing. The students' responses in the post intervention survey also highlighted the students' ability to understand the interdisciplinary nature of manufacturing. This could potentially make it easy to relate their intended major to manufacturing. Through this, perceived relevance to manufacturing shall serve as a precursor to further exploration and may eventually lead to manufacturing being a career consideration.

Conclusion

This study explores the first-year engineering students' perceptions of manufacturing careers. This study elucidates the impacts of sensitizing intervention on engineering students' perceptions through pre- and post-intervention surveys. The responses to the surveys presented the intervention's significant impact on students' perceived relevance of manufacturing to their preferred major and on students' interests towards manufacturing as a career path.

While the findings of this study lay the grounds for further exploration of pedagogical interventions related to manufacturing and its associated impacts, this research has some limitations as well. The students who participated in the survey belonged to only one institution in the US. This presents a lack of representativeness from a national perspective of first-year engineering students. The future research can include multiple institutions for a more representative sample. The second limitation of this study lies in the self-reported data, which may open the room for social desirability bias and agreement bias. Future research can use more robust measurement tools for assessing students' interest and motivation.

This empirical study presents a case for engineering students' early exposure to manufacturing content. With an increase in average perceived relevance of students, sensitizing intervention offers a better insight into manufacturing to the students for making a relatively informed decision in career selection. The practical outcome of this study is the identified need for early, well-structured intervention for engineering students for the purpose of sensitization towards manufacturing as a career path.

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