The Influence of Diversity Dimensions on Student’s Collaboration Success: What It Means for Workforce Development in Manufacturing

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THE INFLUENCE OF DIVERSITY DIMENSIONS ON STUDENT’S COLLABORATION SUCCESS: WHAT IT MEANS FOR WORKFORCE DEVELOPMENT IN MANUFACTURING

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Presented to
the Graduate School of
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by
Oyinkansola M. Adeite
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Dr. Laine Mears, Committee Chair
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Dr. Garrett Pataky
Abstract

Manufacturing productivity is measured by labor productivity which is the hourly output of the manufacturing economy. The recent reduction in productivity numbers by the United States Bureau of Labor Statistics emphasizes the need for workforce development. With globalization and technological advancements, diversity has emerged as a critical aspect for the workplace. By encompassing dimensions such as education, race, and age, diversity creates a tapestry of unique perspectives and experiences. This study’s aim is to figure out the effect of a diversity dimension on team performance using intelligent systems, and in addition, if extra dimensions of diversity further impact team performance. To accomplish this, this study employed a manual assembly process with two human participants and an autonomous agent working together as teammates. It measured build time in minutes, the instances of rework, the number of missing fasteners and the detection of part colour errors. This is compared to the composition of the team’s diversity. Based on the experiment, it was determined that educationally diverse teams had a higher performance than the non-diverse team. It was also discovered that additional dimensions of diversity does not necessarily result in better team performance. This study then elucidates the relationship between diversity and team performance, and greater adaptability of manufacturing companies to dynamic market conditions. Also explaining that manufacturing companies can reap several benefits, spur growth, and survive in today’s cutthroat environment by strategically implementing the appropriate level of technology and intelligent systems. Using a technological road map that details the intended adoption of various intelligent systems over a predetermined time frame results in greater team performance, increased product quality, cost savings and increased competitiveness.
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Chapter 1

Introduction

Manufacturing is the basis of production of tangible goods. It is the combination of various processes and raw materials to create useful products. The manufacturing sector has several benefits to the economy and the community. It provides commercial innovations, contributes to reducing a nation’s trade deficit, satisfies consumer needs and provides high-wage jobs for otherwise low income earners [1]. Manufacturing attracts foreign direct investments in the United States (U.S.) of nearly $1.9 trillion in 2020 [2]. It is responsible for implementing creative and functional designs of various products and processes. The U.S. Bureau of Labor Statistics [3] defines manufacturing companies as establishments that turn resources, substances, or components into products mechanically, physically, or chemically. Manufacturing also provides a range of employment opportunities to workers with different skill sets and education levels. The U.S. Bureau of Labor Statistics reports employment numbers in the manufacturing sector as at December 2022 to be above twelve million workers [4] of the U.S. working population. This is shown in Figure 1.1, which describes a steady increase in employment from the decline in 2020 due to the Covid-19 pandemic. These numbers represent manufacturing being one of the top industries for employment. Manufacturing is viewed as the bedrock of most societies in providing jobs. In the fourth quarter of 2022, manufacturing accounted for $2.90 trillion, 11.1% [2] of the value-added output which is a percentage of the gross domestic product (GDP) in the country as shown in Figure 1.2. The GDP is measured by the value of finished goods and services in the U.S. The value-added output represents wages paid to employees, production and import taxes, gross operating surplus, costs incurred and earnings generated during production. An effort to improve productivity through increased team performance equals an increase in value-added
output of manufacturing in the country. Manufacturing which is responsible for continuous development of goods, adopts technological development of processes and techniques to realize greater outputs. This is evident in the upward trend of technological advancements through each industrial era. From the first industrial revolution characterized by mechanization, to the second and the third industrial revolution brought about by the development of electronics, telecommunications, and computers. The fourth industrial revolution made use of the internet to create cyber-physical systems which are systems in which the hardware and software components work together to fulfill predefined tasks. These progressions as shown in Figure 1.3 brought about the present-day fifth industrial revolution, which is human centered, this is represented in concepts like human-autonomy teams. This concept is discussed in the next chapter.

Data extracted on: January 25, 2023 (1:33:27 PM)

Employment, Hours, and Earnings from the Current Employment Statistics survey (National)

Series Id: CES3000000001
Seasonally Adjusted
Series Title: All employees, thousands, manufacturing, seasonally adjusted
Super Sector: Manufacturing
Industry: Manufacturing
NAICS Code: -
Data Type: ALL EMPLOYEES, THOUSANDS

Figure 1.1: United States Bureau of Labor Statistics: The number of manufacturing employees in the United States from 2020 to 2022 showing a steady increase from the sharp decline recorded at the beginning of 2020[4].

2
Figure 1.2: United States Bureau of Economic Analysis: Manufacturing value added dollar figures from 2021 to 2022[2].

Figure 1.3: Industrial Revolution Progression: Innovations progressed from machinery in Industry 1.0 to Human cyber physical systems in Industry 5.0[5]
1.1 Manufacturing Productivity

Productivity in manufacturing is analysed by different measures. The goal of the analysis affects the productivity metric that is selected. The manufacturing process and the time period being used to estimate productivity must also be taken into account because short-term changes might not correctly reflect long-term trends. Labor productivity is one of the most appropriate productivity indicators for human centered processes. This is due to the fact that it calculates the actual gross domestic product produced in a single hour of labor. Labor productivity is measured by dividing the output of a process by the number of hours worked or calculated as net sales or units produced in relation to labor hours put in by employees. The formula is \( L = \frac{\text{Total output}}{\text{Total input (hours)}} \) where \( L \) is labor productivity. As labor productivity rises, an economy produces more commodities and services for the same amount of relative work. Because of the rise in output, more products and services may be purchased for ever-lower prices\(^7\). A variability in this indicator occurs if there are considerable disparities in the knowledge and experience of the workforce which results in varying outputs compared to hours worked. Another metric of productivity is total factor productivity, also known as multi-factor productivity (MFP), which accounts for all inputs, including labor, energy, capital, and technology. Although more thorough, this indicator is more relevant if the objective is to assess the productivity impact of a specific policy. The calculation is done using the formula \( Y = A \times K^m \times L^n \) where \( Y \) is total output, \( A \) is total-factor productivity, \( K \) is capital input, \( L \) is labor input, \( m \) and \( n \) are shares of output elasticity of capital (K) and labor (L) input respectively. The shares of output elasticity is the percentage by which the output alters when the input does. An increase in any of the inputs leads to an increase in the total output. The paper\(^9\) makes the point that economic policy shouldn’t be solely centered on productivity but on other economic factors, although productivity is a key driver of economic growth. Sreekumar et al. \(^{10}\) underlines how vital innovation and technology are to raising productivity in the manufacturing sector. Using advanced technology in manufacturing can greatly increase productivity and cut costs. Process innovations like lean manufacturing seek to reduce waste and increase value during the production process. They entail getting rid of non-value-added processes such as waiting, overproduction, and excess inventory. They demand an organizational culture shift that prioritizes teamwork and a dedication to continual development. This works with the principle that by lowering lead times, boosting throughput, and raising quality, productivity can increase. Palange et al. \(^{11}\) states
that lean Manufacturing is an essential instrument for increasing manufacturing productivity, and businesses should think about adopting this mindset to stay competitive in the global market. Another process innovation is agile manufacturing. This includes quick iterations, fast fails, and continuous learning to spur creativity and continual improvement. It occurs when rapid customer response is given top priority, speed and agility are then elevated to meet a crucial competitive advantage[12]. Agile manufacturing uses concepts around modular product design and information technology[12]. Productivity in manufacturing is increased using these process innovations. The U.S. Bureau of Labor Statistics, Office of Productivity and Technology (OPT) [13] studies the effectiveness with which the U.S. transforms inputs into outputs of goods and services. Sixty-six (66) of the eighty-six (86) manufacturing industries categorised by the four-digit North American Industry Classification System (NAICS), according to research [?] had losses in labor productivity in 2022 as shown in Figure 1.4. This is one of the reasons to understand methods to improve productivity in teams in manufacturing.

Figure 1.4: United States Bureau of Labor Statistics: The productivity change in manufacturing shown as average annual percentages over seven decades identifies productivity losses in 2022[13].
1.2 Manufacturing in South Carolina

In South Carolina (SC) in the United States, the manufacturing sector has outstanding benefits to the economy. It supports the employment of thousands of workers and generates billions of dollars in revenue in annual direct economic activity[14]. This revenue can be used for the continuous development of the state. Manufacturing supports the economy directly and indirectly, and estimates place the effect of manufacturing on South Carolina’s total economy in the range of $194 billion and $206 billion [14] which accounts for 15.10% of the total output of all industries in the state[15]. According to this level of economic activity, South Carolina would have between 260,300 and 262,391 manufacturing employees [16] as shown in Figure 1.5 and between $34 billion and $37 billion in labor income[14]. Manufacturers in SC account for 16.27% of the total output and employ 12.04% [17] of the workforce in the state compared to manufacturers in whole country who account for 11.39% of the total output and 8.51% of the workforce in the country. Provisions of means of employment in the manufacturing sector has positive effects on other sectors of the economy like real estate and education[14]. Manufacturing in SC provides one of the highest paid wages and benefits to workers. In SC, the average pay for manufacturing jobs is $60,850, compared to $45,694 for all other jobs combined[14]. These figures emphasize the need for workforce development initiatives to continue to positively impact the economy.
1.2.1 Skill Gap

With the current labor shortage [18] and skill gap in industries especially the manufacturing industry[19], it is important to focus on the development of the current and future workforce. The National Association of Manufacturers (NAM) states that the labor shortage and skills gap is anticipated to cause 2 million of the almost 3.5 million manufacturing jobs that need to be filled during the next ten years to remain vacant[17]. The price of those lost employment could reach $1 trillion alone in 2030[13], the average U.S. firm could lose 11% of its annual revenue[14]. Some of the causes of this labor shortage and skill gap includes the changing nature of work, economic expansion, and retirement of baby boomers (those born in the period 1946–1964) [17]. The need to focus on preparing the future workforce with necessary skills is crucial as manufacturing is important to the economic growth of any region. The impact of manufacturing on the economy affects productivity and profitability hence the need to increase focus on skill development. Growing a skilled work-
force makes it more likely that manufacturing will remain relevant in the American economy. The implementation of new manufacturing technologies and techniques like advanced manufacturing has redefined the nature of work and the required human skill needed to fill new jobs. These skills are theoretical, technical as well as relational abilities[20]. Theoretical abilities are gotten from continuous study of materials relating to specific events, it is a style of thinking about potentially connected occurrences. Technical skills are specialised knowledge areas that can be used in math, science, technology, engineering, and the arts in the workplace. Technical skills are often pre-requisites for the use of specific tools and technologies. Relational abilities refers to how successfully we communicate with and relate to others[20]. It is the capacity to engage others and communicate successfully. Building human relational skills like the ability to work in diverse teams is beneficial to increasing team performance[20]. More specific examples of required skills include; interpersonal communication, problem-solving, technology use, leadership, entrepreneurial and informational skills, lean and agile production management, intellectual property management, creative thinking, and the capacity for adaptation[21]. Interpersonal communication which refers to the communication methods between two or more people is especially required when working in diverse teams. These required skills negate the narrative that humans will no longer be needed in the workplace as humans still perform 72% of manufacturing tasks according to a survey done by [22]. Humans play a crucial role in production today and will continue to do so. Not only do humans provide specialized labor, machinery, engineering and programming skills for operational activities in manufacturing, but humans also possess inherent traits that make us unique. Traits like dexterity- performing tasks especially with the hand, adaptability and logical reasoning are skills that are not present in robots available today[22].

1.3 Research Motivation and Approach

This study postulates that if diversity metrics are understood in teams, it may have a positive ripple effect on team performance in the manufacturing industry. As already stated, manufacturing is important and the development of skilled labor in manufacturing is equally as important. The purpose of this study is to understand the influence of diversity in teams as it relates to the manufacturing workforce performance. Diverse teams bring a variety of technical competencies, experiences, and information to the table, which improve problem-solving skills, creativity, and innovation[23].
Manufacturing companies can make use of these advantages to obtain a competitive advantage by understanding the effect of diversity on team performance. Research on the impact of diversity on team performance offers evidence-based recommendations for workforce development[23]. This study will serve to determine the team performance in diverse student teams and bring suggestions on workforce development [23]. The method used in this study is motivated by the paper by Ilgen et al.[24] which describes the input, process and output methods used to understand team performance. The input considers the resources and qualities contributed by team members. The input in this study is the team’s composition which is grouped into educational, age and racial diversity[25]. The process considers team activities. The process in this study is a manual assembly process where team collaboration, coordination and communication is required to complete the process in time and accurately. And finally the output which are the results achieved, for this study is to measure team performance. Surveys from students and companies are then investigated to determine how diversity affects team performance.
Chapter 2

Background

2.1 Diversity

2.1.1 Definition

Diversity is recognized as differences in individuals and how they perceive their environment, react to situations, and make decisions. Diversity is defined as the practice of including or involving individuals from a variety of backgrounds into similar activities. Diversity skills in individuals refers to the conscious awareness of individual differences. To posses this skill is to have cultural awareness and multicultural understanding [26]. Triandis et al.[27] defines diversity as things that affects different aspects of life. The consequences of diversity in human teams can be both positive and negative. A positive attribute is the variety of experiences which can improve performance in teams. The differences however can cause some conflict within teams[28]. The different definitions and aspects of diversity, such as educational and racial diversity relate to the interactions and implications that influence the actions of individuals and organizations. Therefore the significance of taking into account various dimensions of diversity and their relationships rather than concentrating solely on one aspect of diversity is to improve the shortcomings and potential fault areas of one aspect of diversity[26].
2.1.2 Dimensions of Diversity

Education, age, race, gender, religious beliefs, physical and mental aptitude, income level, occupation, language, and geographic location are some of the dimensions that make up diversity. Diversity can also be grouped into features we can not control - oftentimes features that we are born with (Inner Sphere) like age, race, ethnicity and those we can control (Outer Sphere) like religion, income, personal appearance as shown in Figure 2.1. Research on this model of diversity by Lou et al. [29] started the conversations about the parallels and differences that bridge the borders of diversity. They explain that understanding one’s social identities, appreciating what matters, and figuring out how to fit in with society are all essential to ensuring that no sub-group feels excluded or devalued. Of the varying dimensions of diversity, this study focuses on educational, racial and age diversity.

![Dimensions of Diversity](image)

Figure 2.1: Classification of Diversity: This is into two broad groups which are the Inner and Outer Shperes. The inner shpere are features that are beyond a person's control while the outer sphere are features a person can control[29].

2.1.2.1 Educational Diversity

Educational diversity here relates to the differences in spatial and cognitive skills of individuals from different educational backgrounds. Diversity across educational backgrounds and disciplines tends to define how individuals relate in teams and collaborative tasks. The effects of diversity ex-
periences vary across academic learning and personal growth in college students. Hu et al. [30] explains that exposure to individuals and viewpoints that differ from one’s own can promote greater awareness, empathy, and understanding. Engaging with other people and viewpoints can also assist students in expanding their worldview and sharpening their critical thinking abilities. The various avenues via which college students might engage with diversity include; courses, campus clubs, and interactions with individuals from other backgrounds[30]. Maximizing student outcomes in diverse college environments requires a focus on learning productivity and improved performance, which can be achieved through a combination of factors including student motivation, effective teaching, critical thinking and supportive learning environments. Some key points in maximizing student outcomes in diverse environments include[31]:

1. The role of student motivation: A motivated student is more likely to engage in productive learning behaviors, such as seeking out information and participating in class.

2. Effective teaching: Teachers who use active and engaging teaching methods, provide clear and concise information, and create a supportive learning environment can greatly enhance student learning outcomes.

3. Critical thinking: Critical thinking is an important aspect of learning as it helps students reflect on and comprehend their own points of view. It is the capacity to form an opinion or judge if something is right or wrong which aids in understanding, evaluating, and analysing the facts and information at hand.

4. Supportive learning environments: Providing students with access to resources, technology, and adequate support services can increase student motivation and engagement, leading to improved learning outcomes.

5. The importance of student self-reflection: Encouraging students to reflect on their learning experiences and assess their own learning progress can help them identify areas for improvement and increase their motivation to learn.

6. The need for ongoing assessment and improvement: Regularly assessing student outcomes and making adjustments to teaching methods and learning environments can ensure that students are getting the most out of their college experience.
Overall, maximizing student outcomes in college as it relates to diversity requires a commitment to providing students with the resources, support, and motivation they need to succeed[31]. In academia, the most effective and creative teams can be analyzed by examining the vocabulary, methods, and references in published papers of similar topics[32]. Freeman et al. [32] explains that more diverse collaborations tend to use a greater range of scientific vocabulary, different equipment, processes, or data, and more references in comparison to publication works from homogeneous groups. Working with more diverse authors can improve the publication’s quality, its reach, or both since diversity generates a wider range of ideas.

2.1.2.2 Racial Diversity

The U.S. Census Bureau defines race as a person’s self-identification with one or more social groups[?]. In 1997, the Office of Management and Budget (OMB) divided race into five groups that could be easily recognized as:

1. White: Any person whose ancestors came from one of the native peoples of Europe, the Middle East, or North Africa.

2. Black or African American: Any person who is descended from a black racial group in Africa.

3. Asian: Any person who has ancestors in a native group in the Far East, Southeast Asia, or the Indian subcontinent, such as individuals from Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, or Vietnam.

4. American Indian or Alaska Native: Any descendant of an indigenous group in North or South America (including Central America) who continues to identify with their tribe or region.

5. Native Hawaiian or Other Pacific Islander: Any person who has ancestry in one of the Pacific Islands’ indigenous peoples, such as those of Hawaii, Guam, Samoa, or others.

This study focuses on racial diversity as described and not ethnic diversity. Studies show that racial diversity tends to have effects on organizational performance [33] and that businesses with a racially varied workforce are likely to perform better because of the diverse workforce’s improved capacity for creativity, innovation, and problem-solving. However, the level of industry competition has an impact on this relationship. The advantages of racial diversity may be lessened in high-stakes competitive contexts since there may be less possibilities for varied perspectives to be taken.
into account due to the pressure to perform. On the other hand, businesses may be able to fully capitalize on the advantages of racial diversity in low-intensity competitive contexts, which could result in enhanced performance. Andrevski et al. [33] explains that organizations with heterogeneous management teams are more likely to develop and implement novel competitive strategies than are those with homogeneous management teams.

### 2.1.2.3 Age Diversity

Age diversity refers to individuals from various age groups relating together in a team or organization. It includes many different generations, such as Traditionalists (those born before 1946), Baby boomers (those born between 1946 and 1964), Generation X (those born between 1965 and 1980), Millennials or Generation Y (those born between 1981 and 1996), and Generation Z (those born after 1997) are the five generations [34]. Age diversity in teams can facilitate knowledge transfer, mentoring possibilities, increased innovation, creativity and varying skill sets. Age diversity in teams make sharing of information and experience between generations more obtainable. Younger employees often bring new ideas due to new technological proficiency, while older employees may have substantial institutional knowledge and industry expertise. A better decision-making process and increased team performance can result from this insight-sharing. Age diversity offers mentoring and reverse mentoring opportunities. Younger employees can function as mentors, imparting their knowledge and advice to older coworkers, and older coworkers can benefit from the younger employees’ understanding of cutting-edge technologies and trends. This encourages a culture of ongoing learning and growth. A variety of perspectives can result in increased creativity and innovation. When it comes to problem-solving, different generations bring different life experiences, values, and ideas to the table, leading to more well-rounded and creative solutions. Specialized skill sets vary with age. While younger workers are frequently skilled at adapting and adjusting to new tools, older workers may have experience in certain fields. Utilizing the advantages of each age group, teams may build a more adaptable and durable workforce. Asides the identified benefits, issues including communication gaps and potential conflicts may arise as a result of age diversity. The key to overcoming these difficulties and reaping the advantages of age diversity is open-mindedness and effective communication[34].
2.1.3 Diversity in Organizations

Diversity in the workplace can have significant impacts on business performance, both positively and negatively. The Diversity Research Network [35] reports some key points on the effects of diversity on business performance:

1. Positive effects: Increased creativity, innovation, and problem-solving skills can result from a diverse workplace, as can better decision-making and customer satisfaction.

2. Challenges to effective management: Diversity can also lead to conflict and communication difficulties, which can negatively impact business performance if not effectively managed.

3. The importance of technically competent leadership: Good leadership that values and leverages diversity can greatly enhance the positive effects of diversity and mitigate potential challenges.

4. The need for ongoing monitoring and assessment: Organisations must continuously assess and adjust their diversity programs to maintain continuing success because the effects of diversity on corporate performance may change over time.

The study by Kochan et al. [35] explains that the effects of diversity on business performance can be complex and multifaceted, and organizations must be proactive in leveraging diversity for maximum benefit while addressing potential challenges. Katirae et al. [36] explains that human diversity factors play an important role in production system design, and considering these factors can lead to more efficient and effective production systems. These factors include:

1. The impact of diversity on work processes: Understanding how different individuals’ backgrounds, experiences, and abilities can affect their work processes and productivity.

2. The role of diversity in teamwork: Recognizing the benefits and challenges of diverse teams, and developing strategies to effectively manage and leverage diversity in these settings.

3. Diversity-aware systems design: Incorporating diversity considerations into the design of production systems, including the development of flexible and adaptable systems that can accommodate the needs and strengths of diverse workers.

In addition, Lee et al. [37] states that diversity in a team can have favorable effects on how well manufacturing processes innovate. By identifying potential blind spots in material flow that often cause
waste in the production process, diversity of viewpoints can enhance operations and produce better results. For these advantages to be fully realized, the team must embrace diversity and promote collaboration. For managing diversity in a team and enhancing team performance, transformational leadership - which is a style of leadership that influences change in people and systems- can be a useful tool [38]. A collaborative environment that values variety, promotes growth and development among team members is created by transformational leaders. They improve the effectiveness of a diverse team’s collaboration, make the most of each team member’s strengths, and produce superior outcomes by offering this kind of leadership. The traits of transformational leadership can include charisma, individualized care, and intellectual stimulation along with how they can manage diversity and improve team performance. Mannix et al. [39] explains that some disparities, such as those based on backgrounds, viewpoints, and skill sets, can be advantageous and aid in the achievement of the team’s goals. Other differences, such as those based on individual ideas or principles, on the other hand, might cause friction and reduce the efficacy of a team. Identifying which variations are most likely to benefit a team and which ones can cause problems is a delicate balance. Methods for resolving conflicts in a way that improves teamwork, such as encouraging open communication, managing disputes, building a cohesive team by using leadership, and respect among teammates are identified as important diversity skills. Diversity in organizations can have different interpretations and implications, such as:

1. Separation and Silos: Viewing diversity as simply the representation of different groups within an organization, without necessarily promoting togetherness or equal treatment.

2. Variety: Understanding diversity as the addition of different perspectives and experiences, leading to enhanced innovation and creativity within the organization.

3. Disparity and Favoritism: Recognizing the existence of disparities and unequal treatment between different diverse teams, and actively working to address these issues.

Another study by Herring et al. [40] analyzes data supporting the organizational case for diversity, which contends that organizations with diverse workforce are more likely to be profitable. The article states that various aspects of diversity such as race and gender affect various business outcomes. They look at the processes by which diversity may boost productivity which is through more creativity, better judgment, and increased competitiveness. An effective and adaptable production system depends on coordination of diversity. It is important for leadership to understand these different
constructs of diversity and strive for a more diverse workplace that values and leverages the strengths of individuals and teams[41]. Overall, it is important for organizations to actively embrace and leverage diversity in their manufacturing systems to achieve improved performance and flexibility in an ever-changing business environment [42].

2.1.3.1 Demographic Diversity in the Automotive Industry

Demographic diversity in the automotive sector in the U.S, compares the current workforce’s racial and gender composition to the country’s total workforce population[25]. The Table 2.1 from the United States Bureau of Labor Statistics shows the 2022 gender and racial diversity of employees in the Automotive industry. This shows an increase in women employment in the automotive industry from 24% as reported in 2019[25] in Figure 2.2 to 27.6% in 2022. The report of employment in SC automotive industry is shown in Figure 2.3 which is about 5.4% [43] of the workforce. The benefits of demographic diversity in the automotive industry include greater systematic skills and increased competitiveness[25]. American automotive manufacturing sector faces some impediments in boosting demographic diversity such as the under-representation of some particular groups in the hiring pool[25]. This can be addressed by exposure to opportunities and educating diverse student populations to seek careers in the automotive manufacturing sector.
<table>
<thead>
<tr>
<th>Sector of Automotive Industry</th>
<th>Total employed (000)</th>
<th>Women (%)</th>
<th>White (%)</th>
<th>Black or African American (%)</th>
<th>Asian (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicles and motor vehicle equipment manufacturing</td>
<td>1,420</td>
<td>27.6</td>
<td>72.6</td>
<td>17.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Motor vehicle and motor vehicle parts and supplies merchant wholesalers</td>
<td>165</td>
<td>24.1</td>
<td>81.0</td>
<td>11.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Automobile dealers</td>
<td>1,197</td>
<td>21.8</td>
<td>83.4</td>
<td>10.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Other motor vehicle dealers</td>
<td>163</td>
<td>25.5</td>
<td>92.7</td>
<td>3.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Automotive parts, accessories, and tire stores</td>
<td>473</td>
<td>15.1</td>
<td>88.5</td>
<td>6.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Automotive repair and maintenance</td>
<td>1,402</td>
<td>12.1</td>
<td>87.6</td>
<td>6.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure 2.2: United States Bureau of Labor Statistics: National demographic data of women and Black/African American employees in Automotive Industry in 2019[25].

Figure 2.3: United States Bureau of Labor Statistics: SC data of employees in Automotive Industry in 2022[16].
2.2 Team Dynamics

2.2.1 Team Composition

Team composition describes how people are arranged into groups, taking into account their personalities, skills, and abilities. It also refers to the attributes that make up the team, which can either be a homogeneous or heterogeneous team. Homogeneous teams are groups of individuals with similar diversity dimensions while heterogeneous teams are groups of individuals with different dimensions of diversity. Team composition has been used to test performance in diverse groups where a homogeneous team performs a task and is compared with a heterogeneous team. These results are not considered accurate because other factors may be involved in the recorded differences. Factors such as prejudice and discrimination, inter group conflict caused by limited resources[44]. According to a study [45], there is no consistent correlation between people's attitudes, their opinions of other people in their own group, and their attitudes towards those in other groups. When working on a collaborative project, a homogenous team may be more motivated by the prospect of collaboration with members who share similar interests than by the expectation of conflict with members who have different backgrounds. Evan et al.[44] states that the impacts of diversity and homogeneity are not the same. They highlight that one of the opportunities presented by team composition is that choosing team members with similar backgrounds, talents, and experiences has traditionally been the best way to maximize cohesion and reduce conflicts. However, in today’s heterogeneous workplaces, where teams may contain members from different cultures, generations, and functional backgrounds, that approach has become more and more out of date to address the issues brought on by diversity. Understanding each team member’s specific strengths and shortcomings and choosing team members based on their complementing abilities and qualities is a crucial diversity skill for team leaders. An approach is to use assessment tools to assign a more balanced teams in terms of their strengths, weaknesses and abilities. Another approach is to build cross-functional teams with individuals from different expertise and backgrounds, and this can encourage teamwork while also giving people chances to learn from one another and pick up new skills. There is a significance of developing a welcoming workplace that celebrates diversity and promotes open communication in which every team member—regardless of background or identity—feels welcomed and respected. This may result in teams that are more effective, creative, and innovative who recognize the distinct skills and weaknesses of each team member. These studies discussed above show that performance
outcomes can be influenced by both diversity and homogeneity. This is not to suggest that negative effects from working in a homogeneous team do not occur because of variety but that those are not the only reasons. For example, regardless of how well a group performs, individuals in homogeneous teams usually report high levels of confidence[46]. Alternatively, diverse teams are actually closer to an exact measurement of precision than homogeneous teams using objective measures such as speed, accuracy and adherence to instructions to measure performance. Homogeneity will therefore, not be a controlled measure in this study. The experimental methods in this study are designed to compare varying dimensions of diversity and team performance.

2.2.1.1 Human Autonomy Teams

A type of team composition is the Human autonomy teaming (HAT). It is also called human-robot collaboration or human-AI teams and this refers to teams where a human works in association with advanced technology. HAT refers to the interaction of actions and results involving one or more autonomous agent and one or more humans, where each autonomous agent and human is acknowledged as a distinct team member, occupying a specific function on the team, and where the members work together to achieve a common goal. In human-autonomy teams, humans take on different interaction roles with the autonomous agent such as being a teammate, operator, supervisor, bystander or mechanic/programmer[47]. A teammate completes a part of an assembly process while the autonomous agent completes another section while working together. This role is used in this study. An operator is involved in modifying the autonomous agent’s behaviour during operation. A supervisor does not actively control the autonomous agent but watches over it. A bystander does not operate the autonomous agent but is aware of what it is doing and a mechanic or programmer modifies the hardware or software of the autonomous agent.[48]. These roles change depending on the manufacturing environment. The autonomous agent is what gives human-autonomy teaming its autonomy component. It is a computational system that gathers sensory information from its surroundings and determines on its own how to connect the outside input to its behaviors in order to accomplish specific goals[49]. The collaboration between humans and autonomous systems is to achieve a common goal[50]. HAT focuses on improving performance especially in manufacturing. Success of HAT is determined by teamwork, communication and coordination between humans and autonomous systems. Also efficient distribution of tasks between humans and autonomous systems helps in improved team performance. Thomas O’Neil et al. [50] describes human autonomy teaming
levels according to the level of automation present in the team setup as shown in Figure 2.4. For a team to be classified as a HAT, the autonomous agent(s) must meet at least partial degrees of agent autonomy. Partial levels of agent autonomy (Levels 5-6) are capable of recommending and performing acts on their own unless they are vetoed. High levels of agent autonomy (Levels 7–10) don’t require any human input or direction before the autonomous agent takes independent action.

<table>
<thead>
<tr>
<th>Automation Level</th>
<th>Agent Autonomy Level</th>
<th>Automation or Autonomous Agent Role and Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High autonomy</td>
<td>10. The computer decides everything and acts autonomously, ignoring the human.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. The computer informs the human only if it, the computer, decides to.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. The computer informs the human only if asked, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. The computer executes automatically, then necessarily informs the human, and</td>
</tr>
<tr>
<td>Partial</td>
<td>Partial autonomy</td>
<td>6. The computer allows the human a restricted time to veto before automatic execution, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. The computer executes that suggestion if the human approves, or</td>
</tr>
<tr>
<td>Manual control</td>
<td>No autonomy</td>
<td>4. The computer suggests one alternative, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. The computer narrows the selection down to a few, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. The computer offers a complete set of decision/action alternatives, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. The computer offers no assistance; the human must take all decisions and actions</td>
</tr>
</tbody>
</table>

Figure 2.4: Classification of human and agent levels of autonomy: This groups a work team setup into a high or low automation level [50]

The four levels of interdependence in human-autonomy teams by Brian Griffith et al. [51] is shown in Figure 2.5. Pooled interdependence explains a task circumstance in which the task is divided among a number of people, units, or groups, each of whom executes independently with little to no contact or coordination needed and no flow of work between them. Sequential interdependence is when a team member must wait for another member to finish their job before they may start their own. Reciprocal interdependence occurs when team members work together simultaneously as they influence one another’s tasks with inputs from each team member. Intensive interdependence is marked by simultaneous problem-solving and collaboration[52].
Figure 2.5: Human-Autonomy Interactions: There are four levels of interdependence between humans and autonomous agents; Pooled, Sequential, Reciprocal and Intensive Interdependence[51].

Another classification by Endsley et al. [53] as shown in Figure 2.6 describes human-autonomy teams from manual control by the humans to full automation by the autonomous agent. These levels describe the functionality of human-autonomy teams, diversity in these arrangements is considered in order to ensure the appropriate method for each team is chosen to improve team performance.
<table>
<thead>
<tr>
<th>Level of Automation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Control:</td>
<td>The human monitors, generates options, selects options (makes decisions), and physically carries out options.</td>
</tr>
<tr>
<td>Action Support:</td>
<td>The automation assists the human with execution of selected action. The human does perform some control actions.</td>
</tr>
<tr>
<td>Batch Processing:</td>
<td>The human generates and selects options; then they are turned over to automation to be carried out (e.g., cruise control in automobiles).</td>
</tr>
<tr>
<td>Shared Control:</td>
<td>Both the human and the automation generate possible decision options. The human has control of selecting which options to implement; however, carrying out the options is a shared task.</td>
</tr>
<tr>
<td>Decision Support:</td>
<td>The automation generates decision options that the human can select. Once an option is selected, the automation implements it.</td>
</tr>
<tr>
<td>Blended Decision Making:</td>
<td>The automation generates an option, selects it, and executes it if the human consents. The human may approve of the option selected by the automation, select another, or generate another option.</td>
</tr>
<tr>
<td>Rigid System:</td>
<td>The automation provides a set of options and the human has to select one of them. Once selected, the automation carries out the function.</td>
</tr>
<tr>
<td>Automated Decision Making:</td>
<td>The automation selects and carries out an option. The human can have input in the alternatives generated by the automation.</td>
</tr>
<tr>
<td>Supervisory Control:</td>
<td>The automation generates options, selects, and carries out a desired option. The human monitors the system and intervenes if needed (in which case the level of automation becomes Decision Support).</td>
</tr>
<tr>
<td>Full Automation:</td>
<td>The system carries out all actions.</td>
</tr>
</tbody>
</table>

Figure 2.6: Level of Automation: The classification has ten groups from manual control to full automation[53].

The team input to output relationship model is explained by Thomas O'Neil et al. [50] as shown in Figure 2.7. The inputs include characteristics of autonomy like transparency and reliability. Transparency, predictability, and reliability of the autonomous system is important to foster trust. Other inputs are task characteristics, training and human diversity. Working effectively with autonomous systems is made possible by adequate training of humans even from the design phase of the autonomous systems. Training should emphasize the system’s capabilities, constraints, and the best ways to interact with it. Human diversity in a HAT team ranges from experiences, personality and styles[24]. The flexibility of the autonomous system needs to be designed with respect to changes in the work environment and human unpredictable behaviour. Safety is another feature, teams with more human autonomy may provide people with a psychologically safer environment for
sharing knowledge, speculating, coming up with ideas, or reporting uncomfortable information[24]. The process to achieve improved team performance includes proper planning, coordination and communication with the team. Coordination is achieved with shared situational awareness where the environment, tasks, and goals are understood by both the humans and autonomous systems. Planning helps with clear definitions of roles and responsibilities. This will help to steer clear of doubts and potential conflicts. Interaction between people and autonomous systems must be facilitated via clear communication and user-friendly interfaces. The human-autonomy interface can be improved by using techniques like natural language processing, visualizations, and haptic feedback[24]. Natural language processing, a field of artificial intelligence (AI) is concerned with teaching computers to grasp spoken and written language in a manner that is comparable to that of humans. Haptic feedback is the interaction with users through touch while visualizations are represented by actual or imagined production of pictures, diagrams, or animations to convey ideas. The intended output is improved team performance which is evaluated in this study.

Figure 2.7: The inputs such as team composition, training of employees interact with factors such as planning, communication to produces output such as team viability and team task performance[50].

2.2.2 Team Styles

Team styles are explained in several ways, one of which is team work versus task work. Task work refers to what the team does and team work refers to the details of how the team functions[54]. Task related attributes are those features that are closely related to the general work objectives which include key information used to identify tasks. Some attributes are the task complexity, the team’s familiarity with the task, the nature of sub tasks and the time provided to complete the task[55].
These attributes then define the collaboration within the team performing the task. Teams can be synchronous which happens when people work together to accomplish a task or asynchronous teams where one team member works on a part and passes it to the next team member to complete the task[55]. Another attribute is how the link between team structure and performance is impacted by task activity explained by Stewart et al [56]. Teams with a decentralized structure perform better than teams with a centralized structure for complicated and non-routine tasks that call for a higher level of information sharing and coordination[56]. A decentralized structure is one in which lower levels of the organization have been given some sorts of decision-making authority by higher management while a centralized structure is an organizational system where all decisions are made by a single leader or small group. However, for everyday tasks with established methods, such as the experimental approach utilised in this study, the impact of team structure on team performance is less pronounced. In contrast, team work describes the functionality of the team. Trust and communication are attributes of team work[55]. Team work considers the assignment roles in the team, an example is a leader or director who receives information and ensure that the information is distributed and understood by the team members. The variety of the team is another facet of team styles. Team members’ different professional backgrounds and functional areas of competence make up diverse multidisciplinary teams. The level of diversity and the type of task have an impact on the performance of the team[57]. The team members could have similar or different educational or racial backgrounds [55]. When managing diversity in interdisciplinary teams, it is necessary to take team composition, task work, and team attributes into account. The potential of diverse teams can be maximized by matching individuals’ knowledge and abilities to the needs of the work, setting up clear objectives and guidelines, and implementing efficient decision-making procedures[57]. This study assessed participants during the experimental procedures as it relates to diversity and its effects on team performance detailed in chapter four.

2.2.3 Team Collaboration

Team collaboration can be evaluated by how a team interacts and how they process information. How a team uses and processes information can be affected by diversity. A varied workforce with a mix of backgrounds, experiences, and viewpoints can result in the consideration of a greater range of information. This can lead to better decision-making and a higher chance of innovations. Diversity by itself does not, however, ensure better usage of information. The team has to have
efficient mechanisms for communication and cooperation in place. To maximize the advantages of variety in information consumption, managing diversity can also create difficulties, such as navigating divergent points of view [58]. Additionally, Kearney et al. [59] states that diversity can help teams solve problems and make better decisions by bringing a range of perspectives and concepts to the discussion. However, the advantages of variety depends on each team member’s level of cognition or their innate desire to exert effort in their thought processes. Teams with a high cognitive demand are more likely to benefit from diversity by evaluating other viewpoints and coming up with original solutions. Teams with less need for cognition, on the other hand, would find it difficult to successfully assimilate other viewpoints, which would limit the benefits of diversity. The tactics for leveraging the advantages of diversity and encouraging a high requirement for cognition in a team is intended to maximize the information gotten from diversity.

2.2.3.1 Models

A common team collaboration model is the Tuckman’s Stages of Group Development as shown in Figure 2.8. The four phases of team development was first put forth by psychologist Bruce Tuckman[60]. They are Forming, Storming, Norming, and Performing. An updated model includes a fifth stage called Adjourning. Communication between team members is most important to make progress at each stage in this model. In the forming stage, the team members are still getting to know one another and striving to make a strong first impression. The ideal time to create a set of agreed-upon standards, rules, or a team charter is at this stage. Participating in team-building exercises is a smart option in this stage, to promote trust and uncover the varied skills and limitations of the team members. The Storming stage is characterized by frequent interpersonal conflict. Here, initial beliefs and boundaries created by each team member are often tested as people grow more aware of one another’s goals. At this point, team members aim to identify their specific roles in the project while also getting to know one another’s strengths and inadequacies. Understanding how to effectively use conflict and compromise is essential to progressing to the next stage. The Norming stage is next if disagreements are settled in the previous stage which shows flexibility within the team. This results in each team member being conscious of their roles and work on their individual projects. Members may occasionally work separately during this phase, but they must continuously check in with one another to make sure everything is proceeding as expected. To keep everyone on track during this stage, Gantt charts are a crucial tool that may be utilized to make sure that everyone is
accountable to the work and to one another. A Gantt chart is a handy tool for displaying activities or tasks against time. There may be a repetitive forward and backward movement between the three stages at this point until the team members fully know their responsibilities, the objectives of the team, or the bigger goal. Teams successfully complete the performing stage after collaborating on a number of projects, creating a synergy, and creating processes that enable projects to be completed quickly and effectively. Performance-driven teams may work swiftly and cooperatively to complete the task at hand since they take less time to form, storm, and learn to norm. These teams often find adjourning and leaving to be an emotional event. The Figure in 2.9 depicts the sequential model. As the average workforce has expanded in diversity and complexity, it is important to then understand these aspects of team collaboration.

Figure 2.8: Tuckman’s Stages of group development: They are Forming, Storming, Norming, Performing, and Adjourning, the fifth stage was added in an updated model[60].
Figure 2.9: Team Collaboration Progression: The arrows show how a team goes through the five stages of group development[60].

Team conflict could occur while a team goes through the stages of group development explained above. Lencioni’s Five Dysfunctions of a Team outlines five issues that affect team effectiveness and collaboration and are typical among teams. Lencioni et al. [61] suggests that addressing each dysfunction represented by the pyramid shown in Figure 2.10 should be done from the bottom up. The dysfunctions are:

1. Lack of trust: If team members do not trust one another, they are less likely to take chances or ask for help. Lack of trust causes low levels of comfort, which make it difficult to communicate and cooperate effectively as a team.

2. Fear of conflict: While avoiding conflict may lead to peace, it can also hinder progress and creativity. Teamwork naturally involves conflict, which, when handled well, can be very productive.

3. Lack of commitment: The success of the project as a whole may be affected by team members who don’t commit to doing the work, don’t follow through on commitments or decisions, miss deadlines, and disappoint their coworkers.

4. Avoidance of accountability: This demonstrates how willing the team members are to confront each other about actions or performances that could be detrimental to the group.

5. Inattention to results: Team members lose sight of the anticipated outcomes that truly gauge the effectiveness of the team when they place their own ambitions ahead of the team’s aims.
In contrast to the above model, the GRIP model [62] identifies four interconnected elements as shown in Figure 2.11 of very effective team collaboration concepts. They are explained as:

1. Goals: For trust to be established, for team goals to be advanced and for the required outcomes to be produced, the goals of the team members must be in alignment.

2. Roles: The team members must be aware of their responsibilities, the expectations, and the methods of accountability and responsibility.

3. Interpersonal Relationships: Team performance and communication are essential in order to resolve conflict and move forward and for building trust among team members.

4. Processes: This is having a defined procedure for how decisions are made, problems are solved by the team, and conflicts are managed. The work flow and procedures for the team are also established.
Another interesting model to understand team collaboration is the DISC shown in Figure 2.12 by William Marston [63] which describes conflict management methods and measures an individual’s dominant behavioral traits. It makes predictions about behaviors based on his initial four descriptions of four major personality traits: Dominance, Inducement, Submission, and Compliance. More recent revisions describe the models as Dominance, Influence/Inspiring, Steadiness/Supportive, and Compliance/Conscientiousness. The traits are explained as follows:

1. Dominance: The person excels at questioning the current status quo, managing their time well, and organizing their work. Being direct, obstinate, argumentative, too ambitious (taking on too much), disrespectful of authority, and assertive are some of the flaws of this personality trait. The key attributes are a desire to overcome issues, being direct and decisive, enjoying new challenges, being ego-driven, problem-solving, taking risks, and being free from routine.
2. Inspiring/Influential: The individual’s strengths are being a real people’s person who is an excellent negotiator, peacemaker, and innovative problem solver. Lack of attention to detail and a preference for image above practical outcomes are flaws of this personality trait. The key attributes are being emotional, impulsive, persuasive, trusting, enthusiastic, and charming.

3. Steady/Supportive: The individual’s strengths are that they respect authority, willing to compromise, dependable, loyal, empathy and patience which are virtues that help resolve conflicts. The flaws are being susceptible to criticism, resistant to change and difficulty prioritizing. The main characteristics are being empathetic, reliable, a good listener, predictable, friendly, team player, easy-going, and altruistic.

4. Cautious/Compliant: The person’s skills include the ability to characterize circumstances properly and accurately, providing a realistic perspective, being an excellent information gatherer and researcher. The drawbacks include having a hard time taking criticism, a tendency to become bogged down in little details, a need for defined limits, protocols, and a tendency to either avoid conflict or give in. The major traits are respect for authority, high standards, methodical, even-tempered, practical, and logical, as well as a value for correctness and precision.

Understanding the personalities of your teammates is useful while seeking to resolve conflicts.
Another method used to handle team conflicts is the Thomas-Kilmann Conflict Model [64]. Five major strategies are evaluated using a matrix of two scales: cooperativeness, or how much someone tries to meet the needs of others on the team, and assertiveness, or how much someone tries to meet their own demands. The positive and negative impacts of these approaches are:

1. Competing: This description of very aggressive but uncooperative behaviour contains the drive to win at any costs, to dominate, and to take part in power struggles. This could lead to resentment, but it could also motivate coworkers to compete favorably, which, if managed effectively, could lead to creative inventions.

2. Accommodating: This is very cooperative behaviour, yet it lacks confidence. It could appear to be a sensible method to stay out of trouble, but doing so can also result in self-silencing crucial ideas in order to please others, which can breed anger.

3. Compromising: This approach, which is the most moderate on both scales, may appear to be beneficial, but it might lead to discontent and unsatisfactory results. Despite the fact that compromises are occasionally required, the best solutions frequently stem from a single source
4. Avoiding: The least effective strategy to resolve disagreement is to remain silent and uncooperative since this ignores the issue and the need for a solution. But sometimes the best course of action is to ignore the problem and put all of your attention on the good things, especially when finding a viable solution to it seems impossible.

5. Collaborating: The best method to handle conflicts that benefit the entire team and get respect is to be highly assertive and cooperative.

Managing disagreement, obtaining commitment, establishing accountability, and concentrating on results need the development of trust[64]. These five models describe different approaches to ensure effective team collaboration by following stages of group development, understanding personality traits, using positive team collaboration techniques and managing team conflict. Organizations are encouraged to test out which method is most suitable for their team dynamic before implementation.

2.3 Manufacturing Teams

The teams in manufacturing and other industries utilize team composition and collaboration models. A team composition strategy groups teams into static and dynamics models. Static is an assumption that a team’s makeup remains constant across time. The problem with this strategy is that it ignores the fact that team members’ talent levels, experience levels, and willingness to remain on the team can all vary over time. As a result, the other strategy which is to create a dynamic team which assumes a constant change in a team’s description, and model of team composition is more important. An exploration of the evolution of teams in the workplace by Dalcher et al. [52] states that manufacturing companies must move toward a more dynamic and flexible approach to teaming since traditional hierarchical structures are no longer successful in the dynamic and fast-paced corporate climate of today. In order to do this, cross-functional teams that can swiftly adjust to shifting conditions must be established, along with the ability for team members to assume leadership positions. In essence, the modern manufacturing environment requires effective teaming which is crucial for long-term success. Galbraith et al.[65] highlights some of the skills and knowledge required for improved team performance in manufacturing. They are building diverse teams, defining clear goals and tasks, promoting a collaborative environment, practicing good communication and
conflict resolution techniques. Suman et al. [66] argues that behavioural and personality assessments can help manufacturing companies to understand individual strengths and weaknesses, as well as team dynamics, and to develop strategies for improving manufacturing team performance. This helps to tailor training and development programs accordingly, and identify which team collaboration models to utilize. Some other models not mentioned in the above section on team collaboration are:

1. Myers-Briggs Type Indicator (MBTI): The MBTI exam categorises individuals based on their preferences; it does not assess characteristics, competencies, or moral qualities. It can be used to compile and provide information about teams in manufacturing. Understanding personality types often helps team members recognize and value the diversity between people in their team. The test was developed according to a theory of psychological types by C.G. Jung [67]. The theory’s central notion is that people’s seeming irrational behaviour is actually fairly ordered and consistent due to basic differences in how they prefer to use perception and judgement. The exam divides people into one of 16 personality types based on how they prefer to interact with the outside world, and it is divided into four main categories. The four main categories are:

(a) **Favourite World**: This refers to the preference to concentrate on the outside world or one’s own inner world. A person is grouped into either Extraversion (E) or Introversion (I).

(b) **Structure**: This refers to the preference to make decisions up front or to be flexible as one deals with the outside world. A person is grouped into either Judging (J) or Perceiving (P).

(c) **Information**: This refers to the preference of concentrating on the fundamental knowledge one absorbs or interpreting and adding meaning. A person is grouped into either Intuition (N) or Sensing (S).

(d) **Decisions**: This favors considering people and unique circumstances above logic and consistency when making decisions or vice-versa. It is grouped into either Think (T) or Feel (F).

From the four main groups, there are sixteen personality types, which are: ISTJ, ISTP, ESTP, ESTJ, ISFJ, ISFP, ESFP, ESFJ, INFJ, INFP, ENFP, ENFJ, INTJ, INTP, ENTP, ENTJ [67]. To better understand team members’ preferences, manufacturing team leaders can encourage the team to take this exam.
2. Five Factor Model of Personality (also known as the Big Five): Gordon Allport et al. [68]
originally created a list of 4,500 words that describe character attributes. These attributes
were then modified using a method called factor analysis by independent researchers like Lewis
Goldberg, McCrae and Costa to create the big five. There are fifty items on the test, and each
one must be graded on a five-point scale (1=Disagree, 3=Neutral, and 5=Agree) based on how
ture they are about a person. The test believes that there is a spectrum for every personality
feature, an individual is then graded on a scale between the two extremes of the five broad
dimensions:

(a) Individual’s openness: A person values regularity and logic over creativity and spontane-
ity. It describes a person’s ability for intellectual and creative endeavours as well as their
receptivity to new experiences.

(b) Conscientiousness: As opposed to being cautious and disciplined, a person is impetuous
ous and chaotic. It indicates a person’s ability to control their impulses and engage in
behaviour that has a purpose.

(c) Extra version: An individual is withdrawn and introspective versus outgoing and jovial.
It demonstrates a person’s propensity for and degree of desire for social engagement with
their environment.

(d) Agreeableness: An individual is trustful and helpful versus uncooperative and suspicious.
It relates to how people typically treat their interpersonal interactions.

(e) Neuroticism: An individual is calm and assured as opposed to tense and pessimistic. It
describes how a person’s worldview reflects their overall emotional stability.

Although, some critics argue that the MBTI lacks scientific validity and that the personality traits
it measures are not stable over time, it is still a functional tool for assessment. The Big Five
does not adequately account for how various people differ from one another and is more descriptive
than explanatory[69]. Additionally, it fails to effectively address what causes human behaviour.
Instead of being a complete theory of personality, the Big Five was created to organize personality
features[69]. Another limitation of these measures is that they can be easily manipulated or faked by
individuals who want to present themselves in a particular way. These measures recognize personality
diversity dimensions in teams but does not take into account other forms like their educational, age
or racial diversity. Therefore, it is best to use a holistic approach to understanding and improving
team collaboration, and to use instruments as one tool among many for manufacturing workforce
development. Understanding the type of manufacturing environment the team works in is crucial
for creating a cooperative team using the assessments given above. Manufacturing companies can
use a combination of these environments especially when more than one production line is being
run. Bradford Goldense[70] explains that there are five broad categories that can be used to classify
the majority of manufacturing environments, which are:

1. Repetitive: This is an environment that has specific production lines that produce the same
   thing. The production speed used in the production line can be changed to account for
   variations in consumer demand. There is little set-up and change-over work done in this
   environment.

2. Discrete: This environment is really diversified. It includes both infrequent setups and changeovers
   as well as frequent setups and changes. The goods being produced could be quite similar or
   very different. The unproductive set-up and tear-down time increases as the products become
   more dissimilar.

3. Job shop: The production zones are more common than production lines in this environment.
   Similar or different types of products can be assembled in a production zone. If consumer
   demand increases, the environment can be changed to a discrete line, and some labor-intensive
   tasks can be replaced by automated machinery.

4. Batch: This environment can be used in either the Discrete or Job shop environment. The
   goods are created in batches, with each batch’s parts going through a series of steps concurrently
   and in the same order until the batch is complete. Then the equipment is cleaned before
   the subsequent production cycle. Consumer demand can sometimes be satisfied with just one
   batch or in other cases, multiple batches.

5. Continuous processes: This is an environment where the materials are being processed continuously,
   without any breaks or intervals. To create a final product, separate parts are moved from
   one machine to the next. The repetitive environment works well with continuous processes.

Manufacturing team leaders must be knowledgeable about the product design and production en-
vironment to understand when to use machines rather than labor for production[70]. For manufac-
turing teams to deliver better performance, it is best to have a shared goal, complementary talents, specialized knowledge, and innovative skills.
Chapter 3

Research Plan

3.1 Research Objective

The aim of this study is to model the relationship between diversity and team collaborative success. Team collaborative success occurs when a team of individuals from similar or differing backgrounds work together to complete tasks evaluated by predefined performance metrics. The diversity dimensions considered in this study are education, age and race.

3.2 Research Questions

1. Research question 1: Does educational diversity affect student team collaboration success in assembly tasks?

2. Research question 2: Does varying diversity dimensions affect team collaboration success in assembly tasks?

3.2.1 Research Tasks

The overall experimental plan is to simulate a manufacturing assembly process with two human teammates and one autonomous agent. An autonomous agent is a computer system that exists in a dynamic context, observes that environment, and acts freely therein. It accomplishes a set of goals or tasks for which it was designed.[?]. The detail of the experimental plan includes using
a pre-survey to gather demographic and spatial ability of participants before each session, collecting data of assembly errors and the interaction between participants during each experimental session and finally gathering experiential data of participants with a post-survey after the experiments. This experiment was designed to test the performance of diverse and non-diverse teams in a manufacturing assembly process. In relation to research question 1 (RQ1), the qualitative data gathered from the survey was each participant’s college of study in Clemson University. Sign-up was open to participants from all colleges and participants were allowed to sign-up for any session according to their availability. Therefore there was no control of which participants signed up to be teammates for a particular session. Teammates randomly picked each other based on their time availability, they could be from the same college or different colleges. The quantitative data gathered was the total build time of the session, number of missing fasteners in the assembly after the session, detection of part colour errors of the materials and instances of rework performed during the experiment. The task to address RQ1 was designed into the assembly process of the experiment as shown in Table 3.1. An uncertainty of the experiment arises from any participant choosing the "Prefer not to answer" option when asked to state their major(college) in the demographic section in the pre-survey. This provides inconclusive and unusable data for that particular team’s session. The contingency was to recruit more participants to sign-up for the experiments. More sign-ups negate the incomplete information of some of the participants. In relation to research question 2 (RQ2), the qualitative data gathered from the survey was each participant’s race and age to compare the impact of varying dimensions of diversity on team performance. Information about a team mate was not disclosed to the other team mate before or during the experimental session, therefore no prior bias was formed. The task to address RQ2 was designed into the assembly process of the experiment as shown in Table 3.1. An uncertainty of the task could occur if the participant did not provide their complete data for the racial and age diversity dimensions. This could also occur in recruiting only participants with similar racial and age dimensions of diversity. The contingency was issuing invites to a wider pool of students and recruiting more participants.
<table>
<thead>
<tr>
<th>Research Question</th>
<th>Research Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>An assembly activity that has two participants in a team who are either educationally diverse or non-diverse. They complete the assembly of three carts that has a total of nine sub assemblies. The team’s diversity is compared to their build time and three measures of accuracy to understand the effects on the team’s performance.</td>
</tr>
<tr>
<td>2</td>
<td>The assembly activity is done by a team of two participants. The team is racially diverse or non-diverse or age diverse or non-diverse. The process involves nine sub assemblies which include the Upper, Lower and Body parts. Three sub-assemblies make up one cart and the team builds three carts. Results of the team’s build time and three accuracy measures are then recorded. This is compared to the team’s diversity to understand the effects on the team’s performance.</td>
</tr>
</tbody>
</table>

Table 3.1: Research Tasks: The research questions were investigated according to these research task.

### 3.2.2 Hypothesis

The hypothesis of this study is that more diverse teams will improve team performance of the workforce in the manufacturing environment. This study intends to demonstrate that connection by relating the collaboration of students in a learning environment (a University’s campus) to team performance of the manufacturing workforce, aiming to contribute to a more skilled workforce to bridge the current skill gap and labor shortage in the manufacturing industry.

1. Hypothesis 1: Educationally diverse teams positively affect team collaboration success amongst students. This will be tested by measuring the time and accuracy of students in diverse teams to complete assembly tasks and compare with non-diverse teams.

2. Hypothesis 2: Increasing dimensions of diversity in teams negatively affects team collaboration success during an assembly task. This idea will be tested by comparing additional dimensions...
of diversity between diverse student teams and non-diverse teams.

This study postulates that diversity dimensions are important in the manufacturing environment. And the experiments are going to confirm or annul the hypothesis by checking how the team diversity affects team performance.
Chapter 4

Experimental Design and Results

4.1 Experimental Design

4.1.1 Experiment Setup

The experiment space used on Clemson University’s main campus in South Carolina, United States was setup with a human interface station, robot station, a conveyor, workstation, assembly area and warehouse space, as shown in Figure 4.1.
The human interface station had an Ipad setup with instructions to start the experiments or request for new parts. The interface is an interactive screen as shown in Figure 4.2 that is used to "Initialize" the assembly process and request for parts. The interface is a timed sequenced presentation that starts with Initialize. When this is pressed, the researcher handling the autonomous agent retrieves the training kit. Then this goes to the page to request for additional parts, this gives two options of either choosing additional parts or none. Choosing the parts option gives eleven choices of tubes, panels, wheels and connectors. Choosing the none option leads to another Initialize page that begins the experiment session, then the option to request for additional parts is displayed again as shown in Figure 4.3. The interface is designed as a way to interact with the "Agent".
Figure 4.2: Interactive Interface: The interface is used to interact with the autonomous agent to either begin the session or request additional parts.
Figure 4.3: The steps used in the Interface: The Interface starts with Initialize and moves in a timed sequence to request for additional parts.

The autonomous "Agent" is the robot station setup with a Universal robot 16 as shown in Figure 4.4 which was programmed to drag and place the bins filled with parts unto the conveyor. A researcher was stationed behind a curtain at the robot station, acting as the "Wizard of Oz" who places the next bin to be dispensed at the location of the robot, then activates the robot with a button to drag the bin to the conveyor to be released to the participants. The researcher also places
parts in bins as the participants request for it through the interface and then places it at the location of the robot to be dragged to the conveyor and delivered to the participants. The participants were not made aware that a researcher was picking and placing the bins at the location where the robot then drags the bin to the conveyor. They were trained to believe that the agent is a high level autonomous agent which performs tasks programmed to its system independently of a human. The researchers, the interface and another device for video coverage were connected to a zoom meeting that shares the interface presentation to the participants. It also shares the video of the workstation to the researcher which allows the researcher to take measurements of assembly accuracy during the experiment. It allows the Wizard of Oz researcher to monitor the progress of the participants on each sub-assembly in order to know when to place the next bin at the location of robot to dispense the bin to the participants.

Figure 4.4: Universal Robot (UR) 16: The robot is used to dispense the kits in bins.

The conveyor was placed as a link to transport the bins from the robot to the workstation. The workstation was a large table space where the human teammates could pick up the bins from the conveyor, build the sub-assemblies and assembly of the parts in the bin and then place the empty bins and unused parts to on a table to the side of the conveyor. The assembly area was a space used
to place the final assembly of the parts. The warehouse space was for storing additional materials not used during the experiments. The researchers set-up and confirmed the position of all items as shown in Figure 4.5 before each experiment session.

Figure 4.5: Experiment Setup: The bins are delivered through the conveyor using the Universal robot to dispense the bin. The interactive interface is used to Initialize the experiment and request parts from the robot.

4.1.2 Materials

The Funphix material shown in Figure 4.6 was used for the experiments, it is a set of brightly coloured plastic building blocks. The Funphix bill of materials are sets of connectors, tubes, wheels, panels and screws as shown in Figure 4.7, Figure 4.8, Figure 4.9 and Figure 4.10 made of thermoplastic materials and arranged in bins as shown in Figure 4.11 for the experiment.
Figure 4.6: Funphix Materials: The materials are sets of connectors, tubes, panels and screws.

Figure 4.7: Funphix Materials: The sets of connectors and wheel.

Figure 4.8: Funphix Materials: The sets of connectors, tubes, and panels.
Figure 4.9: Funphix Material: The screw used to hold the parts together during the assembly task.

Figure 4.10: The key used to turn the screws during the assembly task.

Figure 4.11: The Funphix materials arranged in a bin for the experiment session.
4.1.3 **Experiment Sessions**

The sessions were developed and carried out by a diverse group of researchers as a "Human Autonomy Teaming" research study under the advisement of Dr. Marissa Shuffler, PhD and Dr. Laine Mears, Ph.D., P.E. The study was designed as a simulation of an assembly process in the manufacturing environment. The study included two human participants and an agent. The role of the agent here was an autonomous robot which dispensed parts for the assembly process. The sessions were carried out using the Funphix materials arranged in bins. The materials were arranged in three categories: Upper shown in Figure 4.12, Lower shown in Figure 4.13 and Body shown in Figure 4.14 frames.

![Figure 4.12: Upper Kit](image)

Figure 4.12: Upper Kit: The kit contains a set of tubes, connectors and panels for the upper sub-assembly.
Figure 4.13: Lower Kit: The kit contains a set of tubes, connectors and panels for the lower sub-assembly.

Figure 4.14: Body Kit: The kit contains a set of tubes, connectors and panels for the body sub-assembly.
These three sub assemblies were built to create one assembled cart. At the beginning of each session, the participants were shown a copy of the informed consent sheet shown in Appendix C. Then the researcher trains the participants through the steps in the training manual shown in Appendix C. The first kit the participants assemble is the training kit from the training bin shown in Figure 4.15 to a completed training kit shown in Figure 4.16. Any errors detected in the training assembly was addressed and discussed. Then the participants are allowed to commence building the sub-assemblies in the Upper, Lower, Body order which makes up one completed cart shown in Figure 4.17. Three completed carts are built to complete the session. Immediately after the build, a post-survey is administered to the participants shown in Appendix B.

Figure 4.15: Training Bin: The kit contains a set of tubes, connectors and panels for training participants during the session.
Figure 4.16: Completed Training Kit: The materials are setup according to the instructions provided during training.

Figure 4.17: Completed Cart: The materials are setup according to the instructions provided during training.
4.1.4 Participants

The participants in the experiment were both undergraduate and graduate students of Clemson University. The participants were encouraged to sign-up for sessions at convenient times on weekdays. The invitations were done through recruitment Flyers shown in Figure 4.18, they were displayed at strategic locations on the main campus. Email invitations shown in Figure 4.19 were also sent via departmental coordinators. Sign up was done using the online scheduling application, Calendly.

Figure 4.18: Experiment Recruitment Flyer: The flyers are a means of advertisement for recruitment to the experiment sessions.
4.1.5 Data Collection

Data was collected in three forms:

1. Pre-survey: A pre-survey shown in Appendix A was sent to each participant via email as shown in Figure 4.20 24 hours before their scheduled session. The pre-survey began with an informed consent sheet shown in Appendix C and then thirteen (13) groups of questions. These questions were administered to collect demographic data and measure the general aptitude of the participants. The questions were multiple choice, short answers, matching and true/false.
Greetings,

Thank you for registering to participate in experiment #IRE2021-0890! This email contains information about participation in your session, which will take place at [time] on [date].

Before you arrive, please complete this pre-survey:
https://dlemson.ca1.qualtrics.com/jfe/form/SV_1FYZF7xme0cmY2g

The session will take place in Brackett Hall room 422. Please be sure to arrive on time so that the session can run smoothly.

If you have any further questions, feel free to reply to this email. I'll be happy to answer all questions you may have.

Best,

Figure 4.20: Pre-survey Email: A sample of an email sent out to participants 24- hours before their scheduled sessions.

2. Observations: During the session, data was collected by two researchers using the "Experimenter Observation Sheet" shown in Figure 4.21 and "Wizard of Oz Observation Sheet" shown in Figure 4.22. The Experimenter observation sheet was used to collect the researcher and each participant’s name, the date of the experiment, instances of rework, other notes, the participant who checks the specification sheet and the participant who uses the interface for each sub-assembly. The Wizard of Oz observation sheet was used to collect the researcher’s name, the date of the experiment, the session start and end time, the type of bin sent, the time the bin was sent and if the participants requested for the bin or not. The researcher sends the next bin by discretion when watching the progress of the participant on each sub-assembly through the zoom session.
Figure 4.21: Experimenter Observation Sheet: A researcher records which participant checks the specification sheet, who uses the interface and instances of rework during the experiment.
Figure 4.22: Wizard of Oz Observation sheet: A researcher records the session start and end time, the time each kit was sent out and if a participant requested for it.

3. Post survey: A post-survey as shown in Appendix C was administered immediately after the experiment to each participant. The post-survey contained five (5) groups of questions. The
groups of questions were in relation to Trust and Distrust, Transactive Memory systems, Task work versus Teamwork, Implicit coordination and Team satisfaction. The post-survey was administered to understand how each team member generally felt about working with their teammate. The answers were ranked using a 6-point likert scale (1, Not at all; 6, Very much so) and a 7-point scale which ranged from strongly disagree to strongly agree.

4.1.6 Measurements

The measurements taken in the experiments are shown in Table 4.1.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Description</th>
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<tbody>
<tr>
<td>Diversity metrics</td>
<td>Educational, Age and Racial diversity</td>
</tr>
<tr>
<td>Assembly Time</td>
<td>The time it took each team to build the assembly measured in minutes</td>
</tr>
<tr>
<td>Assembly Accuracy</td>
<td>This was measured by the detection of part color errors, instances of rework recorded during the experiment and the number of missing fasteners recorded after the experiment</td>
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Table 4.1: Experiment Measurements: The measurements for Diversity, Assembly time and Assembly accuracy were recorded for each experiment session.

The measures for performance used during the experiment are time and accuracy of the experiment. Time is measured by the total build-time of the assembly parts in minutes for each session. The time of the individual sub-assemblies was not recorded in this study. The participants with a shorter time are considered as the better team performance than the participants with shorter time. Accuracy is measured by:

1. The instances of reworks: This is described as the number of times the participants redo/rework the assembly of parts. The researcher records this by observing the participants during the experiment. The participants in a team with fewer instances of rework are considered more accurate than those with more instances of rework during the assembly process.

2. The number of missing fasteners: After the completed assembly and experiment session, the researcher checks the assembled parts for any missing fasteners and records same. The participants in a team with fewer number of missing fasteners in the completed assembly are
considered more accurate than those with more missing fasteners.

3. The instances of detecting part color errors: A part color error was programmed into some sub-assemblies and the participants were trained to detect it by comparing the specification sheets provided with each bin to the parts placed in the bin. Specification sheets as shown in Figure 4.23 are placed in every bin detailing the number and color of parts supposed to be in the bin. The participants are trained to detect the wrong colored part in the bins by looking over the specification sheets once they receive the bin. They are trained to compare the materials in the bin with the materials listed on the specification sheet. The researcher observes the participants during the experiment and records if the participants detect the part colour errors and subsequently request for the correct colored part using the interface as shown in Figure 4.2. The participants in a team who are able to detect the color errors of the parts placed in the bin are considered more accurate than those who detect fewer. The errors specified for each category is below:

(a) Assembly 1: In the Body 1 sub-assembly, there is a wrong yellow color tube in place of a green color tube in this kit.

(b) Assembly 2: In the Lower 2 sub-assembly, there is a wrong red color tube instead of yellow color tube in this kit.

(c) Assembly 3: In the Upper 3 sub-assembly, there is a wrong green color tube instead of blue color long tube in this kit.

The comparison of the analysis of all measures of accuracy shows that the results achieved were similar. Hence, selecting any one of the accuracy measures does not directly influence the outcome of the results.
The demographics data gathered from each participant was used to group participants in a team as either diverse or non-diverse:

1. Educational Diversity: When participants in the team are from different colleges, the team is considered educationally diverse while participants from the same college are considered educationally non-diverse.

2. Racial Diversity: When participants in the team are of different races, the team is considered racially diverse while participants of the same race are considered racially non-diverse.

3. Age-difference diversity: The age difference between participants in a team was measured and grouped into diverse and non-diverse. The team with more than five (5) years age difference between the participants is considered diverse while the team with less than or equal to five (5) years difference is considered non-diverse. This is because a five-year age difference in teams tends to represent variations in life experiences, cultural references, attitudes, and opinions, it typically signifies a significant generational divide[71]. The differences in work attitudes, technological usage, communication techniques, and general thinking between generations can be captured by this age difference. It ensures that there is a good representation of all age groups in this study. It minimizes the influence of individual differences within a given age group while providing sufficient variance to identify significant patterns and trends across the different age groups.

The data on educational, age and racial diversity were collected through the pre-survey.
shown in Appendix A. The racial diversity data is grouped according to the classification by U.S. Census Bureau [7]. For this study, they are Asian, Black/African and Caucasian. The age diversity data is grouped according to five year age groups from the age differences between the participants in a team. They are 18-23, 24-29, 30-35 and 36-41. The educational diversity is grouped according to the categorization of the seven colleges in Clemson University. As at the time of this study, they are:

1. College of Agriculture, Forestry and Life Sciences (CAFLS)
2. College of Architecture, Arts and Humanities (CAAH)
3. College of Behavioral, Social and Health Sciences (CBSHS)
4. Wilbur O. and Ann Powers College of Business (COB)
5. College of Education (COE)
6. College of Engineering, Computing and Applied Sciences (CECAS)
7. College of Science (COS)

4.2 Data Analysis

The one-way Analysis of Variance (ANOVA) is the analytical technique employed in this study to find out whether the means of two or more groups differ from one another [72]. It is a formula for comparing variations in mean (or average) values across different groups[73]. It divides aggregate variability within a data set into systematic factors and random factors. A random factor is gotten from gathering data from a random sample of possible values with the hope that these levels are typical of all levels in that factor. While the systematic factor compares the test to the error variance. The presented data set is statistically influenced by the systematic factors but not by the random factors. Tables in ANOVA produce the probability (p-value) that a statistical summary of the data would be equal to or more extreme than its observed value. Alpha or significance level is defined as the likelihood that the outcome of the study is willing to be wrong. The null hypothesis is the inverse statement of the hypothesis which often needs to be rejected. A null hypothesis can be reliably rejected that a certain model is unimportant when for a given ratio, there is a lower p-value than the significance level (alpha). The F-statistic is defined as the ratio of two variances. Variances
measure the degree to which the data points are uniformly spread around the mean. There are more variations when the individual data points diverge further from the mean. The fact that only one factor and one dependent variable can be analysed is a limitation in ANOVA. When comparing the means of two or more groups, it can show if at least one pair of means is significantly different, but it cannot say which pair.\cite{73}.

### 4.2.1 Data Indices

Thirty-nine (39) experiment sessions were conducted with seventy-eight (78) participants. From this, the data set extrapolated for this study had sixty-four (64) participants which make up thirty-two (32) teams that signed up, did the pre- and post- survey, and participated in the experiments. This difference is because some participants chose the "Prefer not to answer" option when filling the demographic section of the pre-survey which provides data on college, race and age; hence their incomplete data could not be used for this study. The outliers of the total assembly time data was also removed from the final data set used. This is due to the fact that an outlier is an observation in a population-based random sample that deviates abnormally from other values and may negatively affect the results. The demographic data asked in the pre-survey included questions like: What is your age, What is your race and What is your college major. This demographic data was important to inform the diversity data distribution in this study. The demographics in the Table 4.2 and Figure 4.24 depict how the participants in this study were distributed throughout six Clemson University colleges. There were no participants from the College of Agriculture, Forestry and Life Sciences (CAFLS). The distribution of the study’s participants across three racial categories is shown in the Table 4.3 and Figure 4.25. The five years age distribution of the participants used in this study is shown in Table 4.4 and Figure 4.26.
<table>
<thead>
<tr>
<th>College</th>
<th>No. of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>College of Engineering, Computing and Applied Sciences (CECAS)</td>
<td>27</td>
</tr>
<tr>
<td>College of Architecture, Arts and Humanities (CAAH)</td>
<td>1</td>
</tr>
<tr>
<td>College of Behavioral, Social and Health Sciences (CBSHS)</td>
<td>14</td>
</tr>
<tr>
<td>Wilbur O. and Ann Powers College of Business (COB)</td>
<td>10</td>
</tr>
<tr>
<td>College of Education (COE)</td>
<td>1</td>
</tr>
<tr>
<td>College of Science (COS)</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>64</strong></td>
</tr>
</tbody>
</table>

Table 4.2: Educational Diversity Data Distribution: The number of participants in the six colleges of Clemson university who signed-up to participate in the experiment sessions.

![College Data Distribution](image)

Figure 4.24: Educational Diversity Data Distribution: The percentage of participants in the six colleges of Clemson university who signed-up to participate in the experiment sessions.

<table>
<thead>
<tr>
<th>Race</th>
<th>No. of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian</td>
<td>21</td>
</tr>
<tr>
<td>Black/African</td>
<td>13</td>
</tr>
<tr>
<td>Caucasian</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>64</strong></td>
</tr>
</tbody>
</table>

Table 4.3: Racial Diversity Data Distribution: The number of participants in three races who signed-up to participate in the experiment sessions.

65
Figure 4.25: Racial Diversity Data Distribution: The percentage of participants in three races who signed-up to participate in the experiment sessions.

<table>
<thead>
<tr>
<th>Race</th>
<th>No. of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian</td>
<td>47%</td>
</tr>
<tr>
<td>Asian</td>
<td>33%</td>
</tr>
<tr>
<td>Black/African</td>
<td>20%</td>
</tr>
</tbody>
</table>

Table 4.4: Age difference Diversity Data Distribution: The number of participants in four age groups who signed-up to participate in the experiment sessions.

<table>
<thead>
<tr>
<th>Age distribution</th>
<th>No. of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-23</td>
<td>43</td>
</tr>
<tr>
<td>24-29</td>
<td>14</td>
</tr>
<tr>
<td>30-35</td>
<td>3</td>
</tr>
<tr>
<td>36-41</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>64</td>
</tr>
</tbody>
</table>
4.3 Results

Using the Analysis of Variance (ANOVA) tool, the results are thus:

1. Build Time (Mins) vs Educational Diversity: The f-statistic for this comparison is 0.52 with a p-value of 0.47 as shown in Figure 4.27. This analysis shows that there is no statistical significance of the result between the total build time for educationally diverse and non-diverse teams since the p-value is greater than alpha which is 0.05. On average, the educationally diverse team built the assembly faster than the non-diverse team for about 1 minute (27.4 - 26.13) as shown in Figure 4.28. The result suggests that educationally diverse teams performed the experiments faster on average than non-diverse teams as shown in Figure 4.29.
### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Diversity</td>
<td>1</td>
<td>10.98</td>
<td>10.98</td>
<td>0.52</td>
<td>0.475</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>628.99</td>
<td>20.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>639.97</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.27: Analysis of Variance of Build Time (Mins) vs Educational Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

### Means

<table>
<thead>
<tr>
<th>Educational Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>22</td>
<td>26.136</td>
<td>3.968</td>
<td>(24.143, 28.130)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>10</td>
<td>27.40</td>
<td>5.76</td>
<td>(24.44, 30.36)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 4.57890*

Figure 4.28: Mean of Build Time (Mins) vs Educational Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
2. Part Color Error Detection vs Educational Diversity: This analysis shows that there is no statistical significance of the result between the part color error detection for educationally diverse and non-diverse teams since the p-value of 0.65 is greater than alpha which is 0.05. The f-statistic for this comparison is 0.21 as shown in Figure 4.30. The educationally diverse team detected part color errors in the experiment about 0.2 more on average than the non-diverse team as shown in Figure 4.31. The result suggests that educationally diverse teams detected more part color errors intentionally programmed into the experiments on average than non-diverse teams as shown in Figure 4.32.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Diversity</td>
<td>1</td>
<td>0.3551</td>
<td>0.3551</td>
<td>0.21</td>
<td>0.654</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>51.8636</td>
<td>1.7288</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>52.2187</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.30: Analysis of Variance of Color Error Detection vs Educational Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Educational Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>22</td>
<td>1.227</td>
<td>1.378</td>
<td>(0.655, 1.800)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>10</td>
<td>1.000</td>
<td>1.155</td>
<td>(0.151, 1.849)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 1.31483*

Figure 4.31: Mean of Color Error Detection vs Educational Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.32: Color Error Detection vs Educational Diversity: The colleges of the participant’s in a team grouped into diverse and non-diverse teams compared with participant’s detecting error recorded during the experiment session.

3. Instances of Rework vs Educational Diversity: This analysis shows that there is a statistical significance of the result between the instances of rework for educationally diverse and non-diverse teams since the p-value of 0.008 is less than alpha which is 0.05. The f-statistic for this comparison is 8.19 as shown in Figure 4.33. The educationally diverse team had fewer instances of rework with an average of 0.5 compared to the non-diverse team with an average of 2.3 as shown in Figure 4.34. The result suggests that educationally diverse teams had fewer instances of rework during the experiments on average than the non-diverse teams as shown in Figure 4.35.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Diversity</td>
<td>1</td>
<td>21.16</td>
<td>21.164</td>
<td>8.19</td>
<td>0.008</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>77.55</td>
<td>2.585</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>98.72</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.33: Analysis of Variance of Instances of Rework vs College Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

**Educational Diversity**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>22</td>
<td>0.545</td>
<td>1.184</td>
<td>(-0.155, 1.246)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>10</td>
<td>2.300</td>
<td>2.312</td>
<td>(1.262, 3.338)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 1.60784*

Figure 4.34: Mean of Instances of Rework vs College Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.35: Instances of Rework vs College Diversity: The colleges of the participant's in a team grouped into diverse and non-diverse teams compared with the instances of rework recorded during the experiment session.

4. Missing Fasteners vs Educational Diversity: This analysis shows that there is no statistical significance of the result between missing fasteners for educationally diverse and non-diverse teams since the p-value of 0.28 is greater than alpha which is 0.05. The f-statistic for this comparison is 1.19 as shown in Figure 4.36. The educationally diverse team had fewer missing fasteners with an average of 0.95 compared to the non-diverse team with an average of 2.30 as shown in Figure 4.37. The result in Figure 4.38 suggests that the educationally diverse team had fewer missing fasteners on average than the non-diverse teams.
### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Diversity</td>
<td>1</td>
<td>12.45</td>
<td>12.45</td>
<td>1.19</td>
<td>0.285</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>315.05</td>
<td>10.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>327.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.36: Analysis of Variance of Missing fasteners vs Educational Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

### Means

<table>
<thead>
<tr>
<th>Educational Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>22</td>
<td>0.955</td>
<td>1.838</td>
<td>(-0.456, 2.366)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>10</td>
<td>2.30</td>
<td>5.21</td>
<td>(0.21, 4.39)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 3.24065*

Figure 4.37: Mean of Total Fastening Errors vs Educational Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.38: Total Fastening Errors vs Educational Diversity: The colleges of the participant’s in a team grouped into diverse and non-diverse teams compared with the fastening errors recorded during the experiment sessions.

5. Build Time (Mins) vs Racial Diversity: The f-statistic for this comparison is 0.66 with a p-value of 0.42 as shown in Figure 4.39, this analysis shows that there is no statistical significance of the result between the total build time for racially diverse and non-diverse teams since the p-value is greater than alpha which is 0.05. On average, the racially diverse team built the assembly slower than the non-diverse team for about 2 minutes (27.11 - 25.79) as shown in Figure 4.40. The results as shown in Figure 4.41 suggests that racially diverse team performed the experiments slower on average than non-diverse teams.
### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racial Diversity</td>
<td>1</td>
<td>13.83</td>
<td>13.83</td>
<td>0.66</td>
<td>0.422</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>626.13</td>
<td>20.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>639.97</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.39: Analysis of Variance of Build Time (Mins) vs Racial Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

### Means

<table>
<thead>
<tr>
<th>Racial Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>18</td>
<td>27.11</td>
<td>4.73</td>
<td>(24.91, 29.31)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>14</td>
<td>25.79</td>
<td>4.35</td>
<td>(23.29, 28.28)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 4.56850*

Figure 4.40: Mean of Build Time (Mins) vs Racial Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
6. Part Color Error Detection vs Racial Diversity: This analysis shows that there is no statistical significance of the result between the color error detection for racially diverse and non-diverse teams since the p-value of 0.96 is greater than alpha which is 0.05. The f-statistic for this comparison is 0 as shown in Figure 4.42. The racially diverse team detected color errors in the experiment on average about the same as the non-diverse team as shown in Figure 4.43. The result suggests that racially diverse teams detected virtually the same part color errors intentionally programmed into the experiments on average as non-diverse teams as shown in Figure 4.44.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racial Diversity</td>
<td>1</td>
<td>0.0045</td>
<td>0.00446</td>
<td>0.00</td>
<td>0.960</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>52.2143</td>
<td>1.74048</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>52.2187</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.42: Analysis of Variance of Color Error Detection vs Racial Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Racial Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>18</td>
<td>1.167</td>
<td>1.383</td>
<td>(0.532, 1.802)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>14</td>
<td>1.143</td>
<td>1.231</td>
<td>(0.423, 1.863)</td>
</tr>
</tbody>
</table>

Pooled StDev = 1.31927

Figure 4.43: Mean of Color Error Detection vs Racial Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.44: Color Error Detection vs Racial Diversity: The races of the participant’s in a team grouped into diverse and non-diverse teams compared with participant’s detecting error recorded during the experiment session.

7. Instances of Rework vs Racial Diversity: This analysis shows that there is no statistical significance of the result between instances of rework for racially diverse and non-diverse teams since the p-value of 0.65 is more than alpha which is 0.05. The f-statistic for this comparison is 0.21 as shown in Figure 4.45. The racially diverse team had more rework with an average of 1.2 compared to the non-diverse team with an average of 0.9 as shown in Figure 4.46. The result suggests that racially diverse teams had more instances of rework during the experiments on average than the non-diverse teams as shown in Figure 4.47.
**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racial Diversity</td>
<td>1</td>
<td>0.6791</td>
<td>0.6791</td>
<td>0.21</td>
<td>0.652</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>98.0397</td>
<td>3.2680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>98.7187</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.45: Analysis of Variance of Rework vs Racial Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

**Means**

<table>
<thead>
<tr>
<th>Racial Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>18</td>
<td>1.222</td>
<td>1.865</td>
<td>(0.352, 2.092)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>14</td>
<td>0.929</td>
<td>1.730</td>
<td>(-0.058, 1.915)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 1.80776*

Figure 4.46: Mean of Rework vs Racial Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.47: Rework vs Racial Diversity: The races of the participant’s in a team grouped into diverse and non-diverse teams compared the instances of rework recorded during the experiment session.

8. Missing Fasteners vs Racial Diversity: This analysis shows that there is no statistical significance of the result between missing fasteners for racially diverse and non-diverse teams since the p-value of 0.76 is more than alpha which is 0.05. The f-statistic for this comparison is 0.09 as shown in Figure 4.48. The racially diverse team had fewer missing fasteners with an average of 1.2 compared to the non-diverse team with an average of 1.57 as shown in Figure 4.49. The result suggests that the racially diverse team had fewer missing fasteners on average than non-diverse teams as shown in Figure 4.50.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racial Diversity</td>
<td>1</td>
<td>0.960</td>
<td>0.9603</td>
<td>0.09</td>
<td>0.768</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>326.540</td>
<td>10.8847</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>327.500</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.48: Analysis of Variance of Missing Fasteners vs Racial Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Racial Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>18</td>
<td>1.222</td>
<td>1.957</td>
<td>(-0.366, 2.810)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>14</td>
<td>1.57</td>
<td>4.48</td>
<td>(-0.23, 3.37)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 3.29919*

Figure 4.49: Mean of Missing Fasteners vs Racial Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.50: Missing Fasteners vs Racial Diversity: The races of the participant’s in a team grouped into diverse and non-diverse teams compared with the fastening errors recorded during the experiment session.

9. Build Time (Mins) vs Age-Difference Diversity: The f-statistic for this comparison is 1.55 with a p-value of 0.22 as shown in Figure 4.51, this analysis shows that there is no statistical significance of the result between the total build time for age-difference diverse and non-diverse teams since the p-value is greater than alpha which is 0.05. On average, the age-difference diverse team built the assembly slower than the non-diverse team for about 3 minutes (28 - 25) as shown in Figure 4.52. The results as shown in Figure 4.53 suggests that the age diverse teams performed the experiments slower on average than non-diverse teams.
Means

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>10</td>
<td>28.00</td>
<td>5.37</td>
<td>(25.09, 30.91)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>22</td>
<td>25.864</td>
<td>4.074</td>
<td>(23.903, 27.825)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 4.50404*

Figure 4.52: Mean of Build Time (Mins) vs Age Difference Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-Difference Diversity</td>
<td>1</td>
<td>31.38</td>
<td>31.38</td>
<td>1.55</td>
<td>0.223</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>608.59</td>
<td>20.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>639.97</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.51: Analysis of Variance of Build Time (Mins) vs Age Difference Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.
10. Part Color Error Detection vs Age-Difference Diversity: This analysis shows that there is no statistical significance of the result between the color error detection for age-difference diverse and non-diverse teams since the p-value of 0.48 is greater than alpha which is 0.05. The f-statistic for this comparison is 0.50 as shown in Figure 4.54. The age-difference diverse team detected color errors in the experiment on average of 1.4 and the non-diverse team on average of 1.0 as shown in Figure 4.55. The result as shown in Figure 4.56 suggests that age diverse teams detected more color part errors intentionally programmed into the experiments on average than non-diverse teams.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-Difference Diversity</td>
<td>1</td>
<td>0.8642</td>
<td>0.8642</td>
<td>0.50</td>
<td>0.483</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>51.3545</td>
<td>1.7118</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>52.2188</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.54: Analysis of Variance of Color Error Detection vs Age-Difference Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Age-Difference Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>10</td>
<td>1.400</td>
<td>1.265</td>
<td>(0.555, 2.245)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>22</td>
<td>1.045</td>
<td>1.327</td>
<td>(0.476, 1.615)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 1.30836*

Figure 4.55: Mean of Color Error Detection vs Age-Difference Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
11. Instances of Rework vs Age-Difference Diversity: This analysis shows that there is no statistical significance of the result between instances of rework for age-difference diverse and non-diverse teams since the p-value of 0.59 is more than alpha which is 0.05. The f-statistic for this comparison is 0.39 as shown in Figure 4.57. The age-difference diverse team had fewer instances of rework with an average of 0.8 compared to the non-diverse team with an average of 1.2 as shown in Figure 4.58. The result suggests that age diverse teams had fewer instances of rework during the experiments on average than the non-diverse teams as shown in Figure 4.59.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-Difference Diversity</td>
<td>1</td>
<td>1.255</td>
<td>1.255</td>
<td>0.39</td>
<td>0.539</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>97.464</td>
<td>3.249</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>98.719</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.57: Analysis of Variance Instances of Rework vs Age-Difference Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Age-Difference Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>10</td>
<td>0.800</td>
<td>1.549</td>
<td>(-0.364, 1.964)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>22</td>
<td>1.227</td>
<td>1.901</td>
<td>(0.442, 2.012)</td>
</tr>
</tbody>
</table>

*Pooled StDev = 1.80244*

Figure 4.58: Mean of Instances of Rework vs Age-Difference Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
12. Missing Fasteners vs Age-Difference Diversity: This analysis shows that there is no statistical significance of the result between missing fasteners for age-difference diverse and non-diverse teams since the p-value of 0.66 is more than alpha which is 0.05. The f-statistic for this comparison is 0.19 as shown in Figure 4.60. The age-difference diverse team had fewer missing fasteners with an average of 1.0 compared to the non-diverse team with an average of 1.5 as shown in Figure 4.61. The result suggests that the age diverse team had fewer missing fasteners on average than non-diverse teams as shown in Figure 4.62.
Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-Difference Diversity</td>
<td>1</td>
<td>2.045</td>
<td>2.045</td>
<td>0.19</td>
<td>0.667</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>325.455</td>
<td>10.848</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>327.500</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.60: Missing Fasteners vs Age-Difference Diversity: This shows the degree of freedom, sum of squares, mean sum of squares, F-statistic and P-value.

Means

<table>
<thead>
<tr>
<th>Age-Difference Diversity</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverse</td>
<td>10</td>
<td>1.000</td>
<td>2.211</td>
<td>(-1.127, 3.127)</td>
</tr>
<tr>
<td>Non-diverse</td>
<td>22</td>
<td>1.545</td>
<td>3.561</td>
<td>(0.111, 2.980)</td>
</tr>
</tbody>
</table>

Pooled StDev = 3.29370

Figure 4.61: Means of Missing Fasteners vs Age-Difference Diversity: This shows the distribution of diverse and non-diverse data, the mean, standard deviation and confidence interval.
Figure 4.62: Total Fastening Errors vs Age-Difference Diversity: The age difference of the participant’s in a team grouped into diverse and non-diverse teams compared with the fastening errors recorded during the experiment session.

The summary of these findings is found in Table 4.5. Each performance metric is evaluated with the diverse team versus the non-diverse team. The team group with the better performance is shown below:

<table>
<thead>
<tr>
<th>Diversity Metric</th>
<th>Performance Metric</th>
<th>Build time (Mins)</th>
<th>Part color error</th>
<th>Instances of rework</th>
<th>Missing fasteners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational</td>
<td>Diverse</td>
<td>Diverse</td>
<td>Diverse</td>
<td>Diverse</td>
<td>Diverse</td>
</tr>
<tr>
<td>Racial</td>
<td>Non-diverse</td>
<td>Same</td>
<td>Non-diverse</td>
<td>Diverse</td>
<td>Diverse</td>
</tr>
<tr>
<td>Age</td>
<td>Non-diverse</td>
<td>Diverse</td>
<td>Diverse</td>
<td>Diverse</td>
<td>Diverse</td>
</tr>
</tbody>
</table>

Table 4.5: Summary of Results: The results show that the diverse teams had 100% of the team performance metrics for educational diversity. The non-diverse team had 50% of the team performance metrics for racial diversity. The diverse teams had 75% of the team performance metrics for age diversity.
4.3.1 Limitations of this Study

This study did not actively control for the level of autonomous assistance provided by the Universal robot 16 in the assembly task. This study treats the autonomous robot as an equal team mate to the other participants. The human-autonomy team was only a medium for the experiments in this study and not a focus of this study. This study is limited to undergraduate and graduate students of Clemson University, South Carolina. Participants in this study signified interest hence the demographics of the population of this study does not give a complete representation of the diversity present in Clemson University. This study did not also control for the differing background, cultural experiences and departmental levels of each participant. The study analysed only the colleges of each participant for the educational diversity and not the departments (majors). The racial data distribution as shown in Table 4.3 for this study is compared to the racial distribution in U.S manufacturing provided by U.S. Census Bureau as shown in Table 2.1. It shows that this study’s data had 32% Asian distribution compared to 6.8% of U.S manufacturing, Black or African American of 20% compared to 17.7% and Caucasian of 46% compared to 72.6%. Other values were assigned to ethnicity which was not included in this study. This shows that this study had a significantly different and more even racial data distribution. The data for educational and age-difference diversity in the United states was not available at the time of this study for a similar comparison.

4.3.2 Quantitative Measurements

The general conclusions after the experiments are:

1. Build Time: The average build time for all the teams in participation was 26.53 minutes.

2. Missing Fasteners: There were thirty-four (34) fasteners per build, one-hundred and two (102) screws per experimental session. For the all the teams in participation, there were a total of forty-four (44) missing fasteners, which represents 1.35% of total fasteners in the experimental builds.

3. Instance of Rework: There were thirty-five (35) instances of rework.

4. Color errors of parts: There were sixty-six (66) color tube part errors intentionally programmed into the experiments, however all the participants detected thirty-seven (37) errors in total during the experiments which represents 56% of the color tube part errors.
This study can draw the conclusion that, on average, the teams had a good performance which is measured by the time and accuracy levels represented in the assembly. Using a manufacturing metric, throughput time which is the actual length of time needed for a product to move through a manufacturing process before becoming a finished good. The formula is \( TH = I/T \) where \( I \) is inventory, \( T \) is time and \( TH \) is throughput. The throughput for this experiment is 0.339 sub-assemblies per minute where inventory was 9 sub-assemblies and the average time was 26.53 minutes.

### 4.3.3 Qualitative Measurements

#### 4.3.3.1 Participant Post-Survey Measurements

The post-surveys were administered to all participants immediately after the experiment sessions. They were provided online through an Ipad to each participant before leaving the experiment space. It was not timed and the participants were given the privacy to complete them. The participants were asked to rank their views of the experiment in five group of questions utilizing the 6-point likert scale (1, Not at all; 6, Very much so) and a 7-point scale which ranged from strongly disagree to strongly agree. From the five groups of the survey answers analyzed, this is collection of some of the general conclusions:

1. 97% of the participants felt "Assured that this team member made intelligent decisions" while 3% felt otherwise.

2. 99% of the participants felt "Confident that this team member tried to do things that benefited the team" and 1% felt otherwise.

3. 74% of the participants did not feel "Afraid that this team member would make a mistake", 17% felt neutral about this and 9% felt afraid.

4. 54% of the participants did not feel "Compelled to keep tabs on this team member to be sure things got done" while 46% felt otherwise.

5. 6% of the participants disagreed that "Each team member has specialized knowledge of some aspect of our project", while 74% agreed and 20% felt neither.

6. 23% of the participants disagreed that "I know which team members have expertise in specific areas" while 77% agreed.
7. 100% of the participants felt "I am satisfied with my present teammates"

8. 99% of the participants felt "I am pleased with the way my teammates and I work together" while 1% felt neutral about this.

9. 99% of the participants felt "I am very satisfied with working in this team" while 1% felt neutral about this.

These general conclusions are analyzed from the data collected through the post-survey, a sample in shown in Appendix B 29 and 28. This study can then make the conclusion that though the participants worked in teams of educational, racial and age diverse members, majority of the participants did not feel negatively towards working with their teammate.

4.3.3.2 State of Manufacturing Quality: Measurement from Companies

This study references qualitative interviews from the manufacturing workforce. The Clemson University Vehicle Assembly Center conducted interviews to better understand the evolving needs of U.S. assembly manufacturing, specifically around manual assembly quality. The goal of the interviews was to examine the industry’s current state and highlight any needs that should be addressed by technology, companies, education, and research institutions moving forward. An invite shown in Appendix D was sent to several organizations requesting the participation of their employees for a 45 minutes interview conducted remotely. The interviews were one-one with an industry professional and a researcher. The researchers asked a set of questions shown in Appendix D then the transcripts from the interview were recorded in a document as shown in Figure 45. The companies that responded to the invite were automotive part suppliers, original equipment manufacturers (OEM) of luxury vehicles and motorcycles, manufacturers of motor vehicles and a pharmaceutical company. Twenty-five interviews were conducted with the employees and transcribed. Some of the key challenges stated by the participants can be generalized as follows:

1. Workforce Training and communication

2. Tedious recruitment process of the right workers

3. General aptitude of the workers

4. Worker variability in processes, training and engagement
5. Workers not caring about the products and processes
6. Lack of associate understanding
7. Workstation settings variations for ergonomics
8. Learning new tools variation and processes
9. Ensuring worker’s follow safety protocol
10. Equipment errors
11. Prolonged maintenance downtime
12. Role transition
13. Automation of more processes due to fewer workers
14. Workers not as quality minded
15. Lack of cognitive ability
16. Lack of operator understanding and aids
17. Language barrier
18. Unfamiliarity with industry terminology

In addition, a production control and logistics specialist at an automotive supplier believes that the organization at which he works has about 60% people and 40% automation. This means that even though automation is increasing in manufacturing companies, there is still a significant presence of humans occupying positions that require diverse skills. A Quality Lab Supervisor in the same field explains that cross-functional teams are the best method for diversity of perspectives to achieve organization goals. This is further stated in research by Kochan et al. [35] which emphasizes that organizations must be proactive in utilizing diversity for maximum benefit while also addressing the complexity and potential problems of the effects of diversity in organizations. Lastly, a Cross Functional Team Specialist at an automotive company states that workers are usually evaluated by meeting output targets, reduction of top defects per zone and updates to metrics in monthly reports. This relates to the daily manufacturing tasks performed by the workforce. These statements have
drawn this study to conclude that the growth of diverse teams can contribute to the need for continuous workforce development and increased team performance to meet new skill demands and labor shortage.
Chapter 5

Conclusions and Discussion

5.1 Answering the Research Questions

Based on the research, we now understand the following key points about assembly team diversity in relation to performance:

Research question 1: From the results, the significance level and probability value shown in the experiments show that educational diversity does not affect student-team collaboration success in assembly tasks. There is no dependence and statistical significance of the data between educational diversity and team performance in assembly task in this study. However, a larger pool of data might skew these results.

Research question 2: This study also analyzed other dimensions of age and racial diversity. The data showed that the racial and age-diversity also does not affect student team collaboration success in assembly tasks. There is no dependence between racial diversity and team performance in assembly task. There is also no dependence between age diversity and team performance in assembly task.

5.2 Conclusions

The findings from this study using performance metrics and comparison of diverse and non-diverse teams demonstrate that educational diversity has the potential to increase team performance. The review of research papers and real-world experimental sessions has revealed that diversity in
terms of education, race, and age brings together a wide range of perspectives, experiences, and skills, resulting in a more dynamic workforce. The diverse exchange of ideas and viewpoints encourages critical thinking, challenges conventional wisdom, and ultimately leads to better decision-making processes. While the positive impact of diversity on increased workforce performance is evident, it is crucial to acknowledge that reaping these benefits requires more than just increasing diversity in numbers. Manufacturing companies must actively cultivate a culture that promotes collaboration, equal opportunities, and diversity of thought. Initiatives such as training, mentoring programs, and diversity policies can all contribute to creating an environment where diversity truly thrives. However, it is important to note that challenges and barriers to diversity still exist. Systemic biases, lack of representation in leadership positions, and unconscious biases can hinder the full realization of the potential benefits of diversity. In order to increase market share, achieve greater customer satisfaction, and higher cost margins, the leadership of manufacturing companies must actively address these obstacles and implement strategies that promote diversity at all levels, ensuring that diverse voices are heard, and diverse perspectives are valued. In conclusion, this study infers that to bridge the current skill gap in the manufacturing workforce, pursuing a diverse workforce confirms the chances of improving workforce performance. However, careful selection of the dimensions of diversity is essential, as varying dimensions only sometimes yield better performance, as was shown. This provides a case for manufacturing companies to prioritize diversity efforts, recognizing them not only as moral imperatives but also as strategic business decisions. Manufacturing companies should maximize the potential of their workforce by embracing diversity and promoting diversity culture in the work environment. This can boost innovation, improve problem-solving, and ultimately increase performance in a quickly changing global marketplace.

5.3 Recommendations for Further Research

Further research is described as such:

1. A variation of the experiments will be to control the selection of teammates for each experimental session, where an intentionally selected homogeneous team can be compared to a corresponding heterogeneous team. However, this may give room for a bias if the participants are aware of this arrangement and Robert Lount et al. [74] explains that team dynamics and cohesion can be impacted by biased views. This study assumed that there were no pre-
existing bias between the participants because they met right before their experiment sessions commenced.

2. This study did not consider the complexity of manufacturing assembly tasks. Another variation of the experiments is to introduce levels of complexity into the experiments and monitor the learning curve of the participants with each level of complexity.

3. Participants in the study were undergraduate and graduate students of a University, future works can consider non-university students to increase the pool of data. The participants can also be asked to develop a strategy for the assembly process before the start of the experiment. The effects of these strategies will be investigated and compared to teams that begin the process without a strategy in place.

4. This study experimented on three dimensions of diversity which are educational, race and age. Future works can consider experimenting on other dimensions of diversity like gender and cultural/ethnic diversity. The post-survey data in Figure 29 shows that majority of the participants felt confident in their teammate despite the diversity measures. Measuring other dimensions of diversity and comparing with this study might have interesting results.

5. The company interviews shown in Figure 45 referenced only twenty-five employees. A larger sample size and distribution of participants can also be collected spanning across different manufacturing companies.

5.4 Broader Impact in South Carolina

South Carolina being a top manufacturing state, is situated to gain added human resources by contributing to growth of diverse teams in manufacturing. Training eligible students for the workforce increases the chances for employment and in turn positively impacting the economy. The United States Bureau of Labor Statistics shows the number of manufacturing employees in South Carolina to be between 260,300 and 262,391 from 2020 to 2022 as shown in Figure 1.5. This compared to above twelve million employees in the United States as shown in Figure ?? is about 2% of manufacturing employees in the fifty states of the United States. Growing these numbers offers a significant contribution to the economy of the state[14]. The demographic diversity of manufacturing employees in the United states as shown in Table 5.1 shows that growing the diversity pool of
employees is required for the continuous growth of the manufacturing industry especially in SC. The results gotten in this study is especially relevant and impactful for SC manufacturing organizations by understanding the influence of diversity dimensions on team performance.

<table>
<thead>
<tr>
<th>Total employed (000)</th>
<th>Women (% of total)</th>
<th>White (%)</th>
<th>Black or African American (%)</th>
<th>Asian (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12976</td>
<td>29.3</td>
<td>78.7</td>
<td>10.8</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Appendices
Appendix A Pre-Survey Measures

Figure 1: Pre-Survey

<table>
<thead>
<tr>
<th>Item count:</th>
<th>Description</th>
<th>Item Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Demographics (plus furniture question)</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Cognitive Ability</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Sandia Matrices</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Spatial Ability</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>Personality Big 5 short form</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>Locus of Control</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>Adaptability</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Cognitive Style</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Psychological Resilience</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Propensity to Trust</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Propensity to Distrust</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>TAM</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>TRI</td>
<td>20</td>
</tr>
</tbody>
</table>

Total item count: 122

| Demographics | 2 |
| Cognitive Ability | 3 |
| Sandia Matrices | 5 |
| Spatial Ability  | 13 |
| Personality Big 5 | 15 |
| Locus of Control | 16 |
| Adaptability | 17 |
| Psychological Resilience | 18 |
| Cognitive Style | 19 |
| Propensity to Trust | 20 |
| Propensity to Distrust | 20 |
| Technology Acceptance Model | 21 |
| Technology Readiness Index: Optimism Subscale | 22 |
Demographics
Instructions: Please tell us a little about yourself.

1. What is your age?

2. What is your sex:
   □ Male
   □ Female
   □ Other
   □ Prefer not to answer

3. What is your race or ethnic background? (check all that apply):
   □ White/Caucasian, Anglo, European American, not Hispanic
   □ Black/African American
   □ Hispanic or Latino, including Mexican American, Central American
   □ Asian or Asian American, including Chinese, Japanese
   □ Pacific Islander or Native Hawaiian
   □ American Indian
   □ Alaskan Native
   □ Middle Eastern, including Northern African, Arabic, West Asian, and others
   □ Other: Please Describe

4. What is your highest completed level of education?
   □ High School
   □ First year of college
   □ Second year of college
   □ Third year of college
   □ Fourth year of college
   □ Bachelor's Degree
   □ Some Graduate School
   □ Master's Degree
   □ M.D.
   □ Doctorate (e.g., PhD, DNP, JD)
   □ M.D./and other doctorate

5. What is your college major?

6. Please briefly describe any previous work experience.
7. When was the last time you assembled furniture?

Within the past month, 3-6 months, 6-9???

Cognitive Ability
*Taken from International Cognitive Ability Resources (ICAR)*

Verbal Reasoning
1. Isaac is shorter than George and Philip is taller than George. Which of the following statements is most accurate?
   a. Phillip is taller than Isaac
   b. Phillip is shorter than Isaac
   c. Phillip is as tall as Isaac
   d. Isaac is taller than George
   e. George is taller than Phillip
   f. It is impossible to tell
   g. None of these

2. The opposite of a “stubborn” person is a “_____” person.
   a. Flexible
   b. Passionate
   c. Mediocre
   d. Reserved
   e. Pigheaded
   f. Persistent
   g. None of these

3. Joshua is 12 years old and his sister is three times as old as he. When Joshua is 23 years old, how old will his sister be?
   a. 35
   b. 39
   c. 44
   d. 47
   e. 53
   f. 57
   g. None of these

4. Please mark the word that does not match the other words:
   a. Buenos Aires
   b. Melbourne
   c. Seattle
   d. Cairo
   e. Morocco
   f. Milan
   g. None of these
5. Michelle likes 96 but not 45; she also likes 540 but not 250. Which does she like?
   a. 56
   b. 93
   c. 98
   d. 126
   e. 132
   f. 140
   g. None of these

Letter and Number Series
1. In the following number series, what number comes next? 64, 81, 100, 121, 144, ...
   a. 154
   b. 156
   c. 162
   d. 169
   e. 178
   f. 196
   g. None of these

2. In the following number series, what number comes next? 4, 7, 11, 18, 29, ...
   a. 37
   b. 39
   c. 46
   d. 47
   e. 49
   f. 55
   g. None of these

3. In the following alphanumeric series, what letter comes next? I, J, L, O, S, ...
   a. T
   b. U
   c. V
   d. X
   e. Y
   f. Z
   g. None of these

4. In the following alphanumeric series, what letter comes next? V, Q, M, J, H, ...
   a. E
   b. F
   c. G
   d. H
   e. I
   f. J
   g. None of these
5. In the following alphanumeric series, what letter comes next? Q, S, N, P, L, ...
   a. J
   b. H
   c. I
   d. N
   e. M
   f. L
   g. None of these

Sandia Matrices
   a. 10 items from Test #1 used
   b. Instructions:
      i. “Select the answer that completed the pattern below” (answers: 1,2,3,4,5,6,7,8,...)

- Key
  1. A1B4C2 – 8
  2. B3E3 – 8
  3. A3E2 – 3
  4. Z9 – 5
  5. x5 – 8
  6. A3C4E3_3 – 2
  7. Z11 – 5
  8. Y13 – 8
  9. A3D2E4 – 5
  10. X18 – 6

Figure 5: Pre-Survey
Figure 6: Pre-Survey
Figure 7: Pre-Survey
Figure 8: Pre-Survey
Figure 9: Pre-Survey
Figure 10: Pre-Survey
Figure 11: Pre-Survey
Figure 12: Pre-Survey
Spatial Ability

Sample items from the ASVAB Assembling Objects (AO) dimension (available via: https://www.officialasvab.com/assembling-objects-ap/)

1. Which figure best shows how the objects in the left box will touch if the letters for each object are matched?

   ![Figure 1](image1.png)

   a. A  
   b. B  
   c. C  
   d. D

2. Which figure best shows how the objects in the left box will appear if they are fit together?

   ![Figure 2](image2.png)

   a. A  
   b. B  
   c. C  
   d. D

3. Which figure best shows how the objects in the left box will touch if the letters for each object are matched?

   ![Figure 3](image3.png)

   a. A  
   b. B  
   c. C  
   d. D

Figure 13: Pre-Survey
4. Which figure best shows how the objects in the left box will appear if they are fit together?

   a. A
   b. B
   c. C
   d. D

Figure 14: Pre-Survey
Personality Big 5


1. Am the life of the party
2. Sympathize with others’ feelings
3. Get chores done right away.
4. Have frequent mood swings.
5. Have a vivid imagination.
6. Don’t talk a lot. (R)
7. Am not interested in other people’s problems. (R)
8. Often forget to put things back in their proper place. (R)
9. Am relaxed most of the time. (R)
10. Am not interested in abstract ideas. (R)
11. Talk to a lot of different people at parties.
12. Feel others’ emotions.
13. Like order.
15. Have difficulty understanding abstract ideas. (R)
16. Keep in the background. (R)
17. Am not really interested in others. (R)
18. Make a mess of things. (R)
19. Sometimes feel blue. (R)
20. Do not have a good imagination. (R)
Locus of Control

Abbreviated Measure of I-E Locus of Control

1. Many of the unhappy things in people's lives are partly due to bad luck. People's misfortunes result from the mistakes they make.
2. In the long run people get the respect they deserve in this world. Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries.
3. Without the right breaks one cannot be an effective leader. Capable people who fail to become leaders have not taken advantage of their opportunities.
4. Becoming a success is a matter of hard work, luck has little or nothing to do with it. Getting a good job depends mainly on being in the right place at the right time.
5. What happens to me is my own doing. Sometimes I feel that I don't have enough control over the direction my life is taking.
6. When I make plans, I am almost certain I can make them work. It is not always wise to plan too far ahead because many things turn out to be a matter of good or bad fortune anyhow.
7. In my case getting what I want has little or nothing to do with luck. Many times we might just as well decide what to do by flipping a coin.
8. Who gets to be the boss often depends on who was lucky enough to be in the right place first. Getting people to do the right thing depends on ability, luck has little or nothing to do with it.
9. Most people don't realize the extent to which their lives are controlled by accidental happenings. There really is no such thing as "luck."
10. In the long run the bad things that happen to us are balanced by the good ones. Most misfortunes are the result of lack of ability, ignorance, laziness, or all three.
11. Many times I feel that I have little influence over the things that happen to me. It is impossible for me to believe that chance or luck plays an important role in my life.
<table>
<thead>
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<th>Psychological Resilience</th>
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<tr>
<td><strong>Prompt:</strong> Respond to each statement below by circling one answer per row.</td>
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<td><strong>Scale:</strong> Strongly Disagree - Strongly Agree</td>
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<tr>
<td>1. I tend to bounce back quickly after hard times.</td>
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<td>2. I have a hard time making it through stressful events.</td>
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<td>3. It does not take me long to recover from a stressful event.</td>
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<td>4. It is hard for me to snap back when something bad happens.</td>
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<td>5. I usually come through difficult times with little trouble</td>
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<tr>
<td>6. I tend to take a long time to get over setbacks in my life.</td>
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Figure 17: Pre-Survey
Cognitive Style

Instructions: Please indicate the extent to which you personally agree with the following statements.

1. I can easily imagine and mentally rotate 3-dimensional geometric figures. (5)
2. My images are very vivid and photographic. (0)
3. I have excellent abilities in technical graphics. (5)
4. I can close my eyes and easily picture a scene that I have experienced. (0)
Propensity to Trust

Instructions: Please indicate the extent to which you personally agree with the following statements.

1. I usually trust people until they give me a reason not to trust them.
2. Trusting another person is not difficult for me.
3. My typical approach is to trust new acquaintances until they prove I should not trust them.
4. My tendency to trust others is high.

Propensity to Distrust
Source: Lee, Ahn, Song & Ahn, 2018; https://doi.org/10.3390/su10041015

Instructions: Please indicate the extent to which you personally agree with the following statements.

1. I am always careful about trusting people when I first work with them.
2. When I first meet people, I have a tendency of keeping a close eye on their actions.
3. I am always suspicious about new acquaintances until they show me that I can believe them/they are reliable.
4. I hesitate to believe people until they have proved themselves to be trustworthy.
Technology Acceptance Model

Instructions: Please indicate the extent to which you personally agree with the following statements. 1 = extremely likely; 7 = extremely unlikely

Perceived Usefulness
1. Technology enables me to accomplish tasks more quickly
2. Using technology improves my job performance
3. Using technology increases my productivity
4. Using technology enhances my effectiveness on the job
5. Using technology makes it easier to do my job
6. Overall, I find technology useful in my job

Perceived ease of use
1. Learning to operate technology is easy for me
2. I find it easy to get technology to do what I want it to do
3. Usage of technology is clear and understandable
4. I find it cumbersome to use technology
5. It is easy for me to remember how to perform tasks using technology
6. Overall, I find technology easy to use
Technology Readiness Index: Optimism Subscale

Please indicate the extent to which you personally agree with the following statements. 1 - strongly disagree; 5 - strongly agree

1. Technology gives people more control over their daily lives.
2. Products and services that use the newest technologies are much more convenient to use.
3. You like the idea of doing business via computers because you are not limited to regular business hours.
4. You prefer to use the most advanced technology available.
5. You like computer programs that allow you to tailor things to fit your own needs.
6. Technology makes you more efficient in your occupation.
7. You find new technologies to be mentally stimulating.
8. Technology gives you more freedom of mobility.
9. Learning about technology can be as rewarding as the technology itself.
10. You feel confident that machines will follow through with what you instructed them to do.
11. Computers are easier to deal with than people performing the same service.
12. You find you are doing more things now with advanced technology than a couple of years ago.
13. You like the idea of doing business by computer because there is no person to pressure you.
14. People can solve problems more effectively than computers.
15. Society should not depend heavily on technology to solve its problems.
16. People often become too dependent on technology to do things for them.
17. The benefits of new technologies are often grossly overstated.
18. People tell you that you are too optimistic about technology.
19. You find that technology designed to make life easier usually has disappointing results.
20. You want to see the benefits of technology demonstrated before you buy it.

Figure 21: Pre-Survey
Appendix B  Post-Survey Measures

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<td>Transactive Memory Systems - 15</td>
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<td>Taskwork vs Teamwork - 10</td>
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<td>Team Satisfaction - 3</td>
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<td><strong>Total item count: 64</strong></td>
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<td>Team Satisfaction</td>
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Figure 22: Post-Survey
TRUST AND DISTRUST


6-point likert (1, Not at all; 6, Very much so).

Thinking about your human teammate, to what extent did you feel:
1. Assured that this team member made intelligent decisions?
2. Confident that this team member tried to do things that benefited the team?
3. Afraid that this team member purposefully did something that wasn’t helpful?
4. Faith that this team member could do the task at hand?
5. Suspicious about this team member’s reasons behind certain decisions?
6. Confident that you could rely on this team member to try their hardest?
7. Confident in this team member’s ability to complete a task?
8. Nervous that this team member would betray you?
9. Afraid that this team member would make a mistake?
10. Certain that this team member would perform well?
11. Positive that this team member would try and do what is best for the team?
12. Compelled to keep tabs on this team member to be sure things got done?
13. Paranoid that this team member would fail?
14. Cautious about this team member’s intentions for the team?
15. Paranoid that this team member would do something wrong?

Thinking about your agent teammate, to what extent do you feel:
1. Assured that this team member made intelligent decisions?
2. Confident that this team member tried to do things that benefited the team?
3. Afraid that this team member purposefully did something that wasn’t helpful?
4. Faith that this team member could do the task at hand?
5. Suspicious about this team member’s reasons behind certain decisions?
6. Confident that you could rely on this team member to try their hardest?
7. Confident in this team member’s ability to complete a task?
8. Nervous that this team member would betray you?
9. Afraid that this team member would make a mistake?
10. Certain that this team member would do as they said?
11. Positive that this team member would try and do what is best for the team?
12. Compelled to keep tabs on this team member to be sure things got done?
13. Paranoid that this team member would perform well?
14. Cautious about this team member’s intentions for the team?
15. Paranoid that this team member would do something wrong?
TRANSACTIONAL MEMORY SYSTEMS


5-point disagree–agree response format, in which 1 strongly disagree, 2 disagree, 3 neutral, 4 agree, and 5 strongly agree.

Thinking about your human and agent teammates, please rate the extent to which you agree with the following statements.

**Specialization**

1. Each team member has specialized knowledge of some aspect of our project.
2. I have knowledge about an aspect of the project that no other team member has.
3. Different team members are responsible for expertise in different areas.
4. The specialized knowledge of several different team members was needed to complete the project deliverables.
5. I know which team members have expertise in specific areas.

**Credibility**

1. I was comfortable accepting procedural suggestions from other team members.
2. I trusted that other members’ knowledge about the project was credible.
3. I was confident relying on the information that other team members brought to the discussion.
4. When other members gave information, I wanted to double-check it for myself. (reversed)
5. I did not have much faith in other members’ “expertise.” (reversed)

**Coordination**

1. Our team worked together in a well-coordinated fashion.
2. Our team had very few misunderstandings about what to do.
3. Our team needed to backtrack and start over a lot. (reversed)
4. We accomplished the task smoothly and efficiently.
5. There was much confusion about how we would accomplish the task. (reversed)
**TASKWORK VS TEAMWORK**
Crawford and Lepine 2003

Taskwork: “based on the tasks members are jointly involved in”
Teamwork: “how team members interact to accomplish those tasks”

1=Never, 2=Rarely, 3=Occasionally, 4=Sometimes, 5=Frequently, 6=Usually, 7=Every time

In regards to your **agent** teammate, please rate the extent to which you...

1. Worked with this teammate to complete this task? (taskwork)
2. Coordinated and integrated your work? (coordination - A)
3. Tracked team resources? (systems monitoring - A)
4. Discussed the team’s tasks, the resources you need, and the challenges you faced? (mission analysis - T)
5. Set and prioritized goals? (goal specification - T)

In regards to your **human** teammate, please rate the extent to which you...

1. Worked with this teammate to complete this task? (taskwork)
2. Coordinated and integrated your work? (coordination - A)
3. Tracked team resources? (systems monitoring - A)
4. Discussed the team’s tasks, the resources you need, and the challenges you faced? (mission analysis - T)
5. Set and prioritized goals? (goal specification - T)
IMPLICIT COORDINATION


Instructions: Please rate the extent to which you agree with the following statements about your human-agent team:

1 - strongly disagree;  2 - disagree;  3 - somewhat disagree;  4 - neither agree nor disagree;  5 - somewhat agree;  6 - agree;  7 - strongly agree

1. Members of my team provided task-related information to other members without being asked.
2. My team proactively helped individual members when they needed assistance.
3. My team monitored the progress of all members' performance.
4. Members of my team effectively adapted their behavior to the actions of other members.

Figure 26: Post-Survey
TEAM SATISFACTION

Please rate the extent to which you agree with the following statements.

1 = strongly disagree; 2 = disagree; 3 = somewhat disagree; 4 = neither agree nor disagree; 5 = somewhat agree; 6 = agree; 7 = strongly agree

1. I am satisfied with my present teammates.
2. I am pleased with the way my teammates and I work together.
3. I am very satisfied with working in this team.
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<td>Very much so</td>
<td>Not at all</td>
<td>Very much so</td>
<td>Very much so</td>
<td>Not at all</td>
<td>Very much so</td>
<td>Not at all</td>
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<tr>
<td>26</td>
<td>Very much so</td>
<td>Very much so</td>
<td>Not at all</td>
<td>Very much so</td>
<td>Very much so</td>
<td>Not at all</td>
<td>Very much so</td>
<td>Not at all</td>
</tr>
</tbody>
</table>

Figure 29: Post-Survey Data
Appendix C  Experiment Materials

C.1 Informed Consent Sheet

Informed Consent to Participate in Research Study

Principal Investigator(s): Marissa Shaffer, Ph.D.
Graduate Student Researchers: Sydney Begerowski, Flanagan Waldberr, Jacob Biddlecom
Sponsor: National Science Foundation
Investigational Site: Clemson University
Contact: sbegarow@clemson.edu

Introduction: You are being invited to take part in a research study. To be included in the research study you must be 18 years or older, able to comfortably lift 10 lbs, and able to stand and walk short durations (e.g., 1,000 ft) intermittently for an extended period (i.e., 3 hours). Please note persons at higher risk of severe illness from COVID-19 (e.g., older adults, people with medical conditions) are currently excluded from research participation.

Purpose of the research study: The purpose of this study is to develop a better understanding of how to optimize teamwork between both human and artificial agents in a manufacturing context. The research study will be used for academic presentations and publications, potentially including theses and dissertations.

What you should know about a research study:

- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.

What you will be asked to do in the study: You will be asked to complete an experimental session involving a series of assembly tasks with your teammates. During the experiment session (approximately 1.5 hours total), audio and video data will be collected via video cameras and researchers will also be present to observe behaviors. Prior to arriving at the experimental session, you will be asked to complete an online survey about yourself that should take approximately 30 minutes. Please note all research must adhere to local university guidelines regarding COVID-19 precautions (e.g., health checks, wearing a mask, physical distancing). Please feel free to reach out to your university co-principal investigator for updated information on these guidelines (see below).

Study Participants: You are one of about 1,000 participants.

Time required: Approximately one hour and thirty minutes.

Funding for this study: National Science Foundation (NSF). The researchers confirm that there are no conflicts of interest, financial or otherwise, that would compromise the integrity of the work.

Benefits: There are no expected benefits to you for taking part in this study.

Compensation: You will receive course credit (8) for taking part in this study. Participants can withdraw from the study at any time without penalty. Compensation in SONA points will reflect the amount of time they participated in the experimental session. Participants who complete the pre-survey, but who choose not to participate in the experimental session, will not receive compensation.

Risks: The experimental session is contains physical activity (lifting objects less than 10lbs). Otherwise there are no reasonably foreseeable risks or discomforts to your participation beyond normal daily activities.

Figure 30: Informed Consent Sheet
Please be aware COVID-19 is a general risk to the public and is not unique to participating in this study. The exposure risks for COVID-19 are no greater than those ordinarily encountered in daily life for example traveling by public transportation, touching contaminated surfaces, or walking to class. Any exposure risk for contracting COVID-19 is not a research-related risk and subsequent impacts are the sole responsibility of the participant.

Confidentiality: Confidentiality of the research records will be strictly maintained. The data will be collected on a secure server. All files will be password protected before transmission and/or storage. The output of the study will be based on an aggregation of data collected from multiple informants. Diligent care will be taken to protect identities and sensitive information. Only research team members, who have all completed research ethics and compliance training (CITI), will have access to the data. As a part of their responsibility to protect human volunteers in research, the IRB at Clemson University will have access to the research records. Participants’ sensitive information may be shared with representatives of Clemson University or governmental authorities if or someone else is in danger or if we are required to do so by the state law.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, email Sydney Beigerowski at sbegoro@g.clemson.edu

IRB contact about your rights in the study or to report a complaint: Research at Clemson University involving human participants is carried out under the oversight of the Institutional Review Board (Clemson IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, Clemson University, Office of Research Compliance (ORC). You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

For questions about your rights as a research participant, or to discuss problems, concerns or suggestions related to the research, or to obtain information or offer input about the research, contact if you have questions pertaining to your rights as a research participant, or to report objections to this study, you should contact the Compliance Administrator, at Clemson University. Email: irb@clemson.edu or Telephone: 864-656-0036.

Withdrawal from the study: You have a right to withdraw your data from this study at any time. To withdraw from the study, simply tell the researcher that you no longer wish to participate. The sponsor or investigator can end the research study early. If you do not follow the instructions of the research staff, the investigator may remove you from the research without your approval. We will tell you about any new information that may affect your health, welfare or choice to stay in the research.

Your decision to take part or not in this study will not affect your grades, your relationship with your professors, or standing at your University.

By selecting "I CONSENT" below, you agree that:

- I have read and understood the above information
- I voluntarily agree to take part in the procedure
- I can lift 10 lbs
- I can stand and walk short durations (e.g., 1,000 ft) for an extended time period (i.e., 1 hour)
- I am at least 18 years of age or older
- I will abide by campus and research policies regarding COVID-19 (e.g., mask requirement, physical distancing, access to only designated areas)
- I am NOT at higher risk of severe illness from COVID-19

Figure 31: Informed Consent Sheet
C.2 Training Materials

RESEARCHER COPY: GENERAL TRAINING

WELCOME

“Hi [Name] and [Name], Thank you for volunteering to participate in our study today. Here is a copy of the informed consent sheet that you agreed to in the pre-survey. Before we get started, we are going to go through some training together to help your performance on today’s task.”

EXPERIMENT OVERVIEW

“For this experiment, you and your team will be tasked to build three carts (pictured to the right). First, you and your team will build one cart from start to finish. It is important that you complete one full cart before you begin building the next cart. You will then complete this process for cart 2, and again for cart 3. Do your best to maximize your team performance by completing the carts quickly and accurately. You are limited to one hour to complete the experiment.”

BUILDING CARTS

“To build one full cart, you need to follow three sub-assemblies: the upper frame, the lower frame, and the body. The sub-assemblies are:

1. Upper frame (image 1), which includes the cart opening and handle
2. Lower frame (image 2), which includes the base and the wheels
3. Body (image 3), which requires you to attach the upper and lower frames together


Figure 32: Training Material
**Building a Kit**

“Parts for each sub-assembly will be given to you in a kit. One kit contains the parts necessary to build one of three sub-assemblies. The kit will also contain a specification sheet (pictured below). This sheet tells you:

- What parts you need
- How many parts you need
- The colors of the parts you need

You must build carts accurately. That is, the parts on the specification sheet must match those used in the completed product.”

![Diagram of a kit]  

“**When you complete a sub-assembly, place it on the table where it is marked “Completed Kits”.** Once you have built each sub-assembly, you will complete the cart by attaching the outer panels to the body (Image 4). When you complete a cart, wheel it to the area on the floor where it is marked “Completed Carts.””

**Performance**

Your team will receive a score based on how well you perform. You will be assessed based on your ability to:

1. Build the carts accurately
2. Build the carts quickly

*Failure to meet these requirements will result in points being deducted from your team.*

**Stop and Ask:** “Do you have any questions so far?” Usually this will be a no, but be sure to ask just in case.

---

Figure 33: Training Material
PHYSICAL SPACE

BUILD AND STORAGE AREAS

"The main table in the center of the room is the designated build area. When building each cart, you and your team may not leave the designated building area. The storage area is behind the dividers and assembly line. In the storage area, there is a physical artificial agent that will load the parts onto the assembly line as you need them. To preserve your safety, please do not enter this area."

MATERIAL AREAS

"Areas you will use:

- **Completed kits**: Use this space on the table to place completed kits (upper or lower frame).
- **Completed carts**: Use this space on the floor to place completed carts.
- ** Rejects**: Use this black bin to place parts or kits you do not need if you receive any. You cannot take parts from this bin after placing them here.
- **Empty bins**: Use the table adjacent to the assembly line to place empty bins."

STOP AND ASK: "Any questions about the space or material areas?"
TEAM INFORMATION

"Your team will consist of yourself, one other teammate, and one agent."

YOUR ROLE

"Your role is to work with your teammates to complete three full carts. You must work together to complete the carts efficiently."

WORKING WITH YOUR AGENT

"One of your teammates will be an agent located in the storage area behind the dividers and assembly line. This teammate’s primary function is to monitor your progress through a camera and send you kits as you conclude a build. The agent also has an interface, which has buttons for each possible part (pictured below). Should you desire a different part than originally sent, you can indicate which you would like to receive by pushing the button that corresponds to the desired part. Your agent teammate will then send you the requested materials."

"Failure to adhere to the aforementioned rules will result in dismissal from the experiment and you will not be fully compensated for participation."

STOP AND ASK: "Any questions before we move on to the assembly training?"

Walk over to the interface. You will motion to it during the next part of your instruction.

Figure 35: Training Material
RESEARCHER COPY: ASSEMBLY TRAINING

"The next part of your training is the assembly training. This is where you practice working with your teammate and building materials. This first page has a list of materials that you could interact with during the experiment, so you should try to familiarize yourself with them."

Go to the next page.

In this document, you will be provided information about the materials you will be using to assemble the carts.

Identifying Materials

You do not need to worry about identifying the proper materials for each cart. Your artificial agent will do this for you.

List of Materials

Below, you will find a list of the provided materials that you will be using during the experiment. Please familiarize yourself with them.

Figure 36: Training Material
**Practice Component**

“When you’re ready, you will press the initialize button. This is how you tell your agent teammate that you’re ready to begin. The agent will send you your training kit, which has instructions on what to build. You will work together to complete the training. I will be sitting on the side of the room, and will not help you during training. You can let me know when you’re done and I will review your work. I recommend following the instructions on this page step by step. Any questions?" if yes, answer them.

“Allright, go ahead and hit initialize to begin.” Move to the side of the room while they complete training.

**Don’t Read This To Them.** You should be sitting on the side of the room. Jump below for how to talk to participants after training.

---

**Part 1: Get the Kit and Verify Contents**

Obtain the kit from your agent. Press initialize to let your agent teammate know you’re ready. Once the kit is at the bottom of the assembly line, bring it to the build area. Verify the kit contents by looking at the specification sheet, then proceed to step 2.

---

**Part 2: Connecting Tubes and Connectors**

You will now practice by connecting a few of the base materials together to build a frame (pictured below).

* Step 1: Slide a connector into one of the open ends of the tubes.
* Step 2: Line up the respective holes.

---

**Figure 37: Training Material**
Practice Part 3: Add A Panel to Your Structure

You will now practice adding panels to a structure (pictured below).

- Add a panel to the square. Pop the panel into the frame. You do not need to screw in the panel.
- When doing so, you may feel a bit of resistance, but this is ok. You will not break the panel.

Once you are finished, check with a research assistant to ensure you have done this correctly.

At this point, they should approach you about finishing training. Check their work. You should say something along the lines of:

"Great job! There's a few things I want to point out to make sure you understand how to work with the material:

Figure 38: Training Material
1. The screws only need to be turned 90 degrees. Just one quick turn will set the screw. You
don’t need to turn the key multiple times.
2. Notice how the materials in the kit matched both the number and colors specified on
the kit sheet that came in the bin. That’s good.
3. Sometimes you might feel some resistance from the tubes or connectors. That’s ok, you
can just push them together with a little bit of force.
4. Notice how the interface has the options for you to select parts. Since you didn’t need
anything, I’m going to hit “None” to reset it. **Wait over to the interface and hit none.**

“Now I have two questions for you:

1. If this were a completed kit, where would you place it? **Gesture to the completed**
   training build. Make sure the participants know it would go in the “completed kits” area
   marked with yellow tape on the table.
2. And where does the empty bin go?** Make sure the participants move it to the empty bin
   table if they have not already.

“Alright, the final step is a short quiz. Please fill this out, then we’ll go over the answers together.”

**Wait until both participants are done with the quiz. Then, read each question, followed by the**
correct answer. You do not need to take their quizzes and formally grade them.
**Teaching Assessment**

**Question 1:** How will your performance be graded?

A. Speed - the faster the better  
B. Accuracy - the carts should all be correct  
C. Both speed and accuracy  
D. Neither - performance isn’t graded

**Question 2:** You need to build carts accurately. How do you check for accuracy?

A. Make sure all of the parts you need are in the kit  
B. Double check that all of the parts match the colors specified on the sheet  
C. Check that both number of parts and color of parts match the kit sheet  
D. Ask the agent to double check accuracy for you

**Question 3:** Where should you place empty bins and extra parts?

A. Both go on the “Rejects” bin  
B. Extra parts go in the “Rejects” bin and empty bins go on the “Empty” table  
C. Extra parts go on the “Empty” table and empty bins go in the “Rejects” bin  
D. Both go on the “Completed Kits” section of the table

**Question 4:** Can you retrieve parts for use once placed in the reject bin?

A. Yes  
B. No

**Question 5:** How many carts do you need to make in total?

A. 1 cart  
B. 2 carts  
C. 3 carts  
D. 4 carts

Once you are done reviewing the quiz:

"Do you have any other questions for me before we get started?"  
Answer any questions they have.
“Alright, I will be in this room (gesture to second office) while you complete the experiment. You can come get me once you finish building the third cart. To officially get started, hit initialize on the interface. Good luck!” Take the assembled training frame with you so it’s out of their way.

For During/After:

Go into the office, and close the door so it remains cracked enough that you can still hear. Observe them via Zoom and track progress on the observation sheet.

After they complete the experiment, go out there and say:

“Thanks for completing this experiment! You did great! The final step is a short post-survey. It should only take a few minutes. Once you complete this, you are free to go. We will email your payment.” Hand them the iPads and answer any final questions they might have after they finish the survey. Do not answer any questions prior to them completing the survey.

Thank them one last time for participating!

Figure 41: Training Material
Appendix D  State of Manufacturing Quality Interview Documents

The Clemson University Vehicle Assembly Center is working to better understand the evolving needs of US assembly manufacturing, specifically around manual assembly quality. The goal of this work is to examine the industry’s current state and highlight any needs that should be addressed by technology, companies, education, and research institutions moving forward.

We also seek to understand better the pain points that might be common across industries or specific manufacturing segments and how companies are approaching quality for their manual assembly processes. The data-driven learned outcomes will help target our research efforts and those of other institutions where they will be most beneficial to the manufacturing industry’s needs. We will also be supplying the anonymized final report to all participants to help readers gauge their organization or production area, which we hope will provide value to them.

The format is a <45 minute one-on-one interview where everything shared will be anonymized, both by person and company. We aim to interview multiple levels of individuals, including workers, line managers, engineers, and plant management. We will complete >100 interviews by Q3 2022 and release the results in the subsequent quarter to all participants.

We would greatly appreciate it if you could share your experience with us.

To schedule an interview, please use the online form at the link below.
https://clemson.edu/vehicle/state_of_manu

Regards,
Matthew Kough, Ph.D.
Postdoctoral Research Fellow
Clemson Vehicle Assembly Center (CVAC)
College of Engineering, Computing and Applied Sciences
Clemson University
575 Millennium Blvd
Greenville, SC 29607
mkough@clemson.edu
(423) 465-7764

Figure 42: State of Manufacturing Quality Interview Request Letter
Summary of what, summary of what we are asking about (how are we doing it), and possibly a quick summary of some interesting points/call to action

Prep Discussion:
- understanding how companies and individuals are approaching quality for manual assembly processes in today’s manufacturing
- Focus is on the current and past, not the future
- There are no right or wrong answers
  - Ask to record audio only (begin recording voice only)

ADD GAIN POINTS (opposite pain points)

Seed Interview Questions:
- What is your position/role in the company? How long have you been in this role?
- What mix of people to automation exists?
- How is quality defined in your company? What performance indicators of the product or process are evaluated? **Need to reword this question**
  - Do the quality metrics change over time for the same product?
  - **Bonus related to quality?**
- Who sets the quality standards?
  - How are quality standards revised?
  - Why would the quality standards be revised?
  - Have you set new quality metrics due to changed quality evaluation methods?
  - These will be anonymized to general topic areas:
    - What are the key pain points that exist in your factory?
      - Around people
      - Around processes
      - Around tools used to measure quality
      - Around product in assembly
      - What are the key gain points that exist in your factory?
- What types of methods or types of tools do you use to evaluate quality?
  - Who makes the purchasing decision for them?
    - How were they (the people) selected?
    - What do you look for in new quality tools during the selection process?
Figure 44: State of Manufacturing Quality Interview Script

- Who influences the purchasing decision for new tools and methods?
- Is it someone’s role to look for new methods and tools?
  - If yes, how do you work to stay up to date or search for new tools?
- What metrics are used to evaluate new methods or tools?

- Who evaluates the quality of the products and processes?
  - What education and training are provided to your workforce to interact with new tools and methods?
    - **What have you tried in the past (Different training)?**
  - How do workers know that they have been successful?
  - Do you find the methods used to be objective in nature?
  - Would a more objective tool be preferred over more subjective tools if overall they result in the same number of caught defects?
    - **Build the why back into the question more**

- Questions on FMIG team topics
  - Nate McNeese
  - Chris Flahman
  - Wen
  - Joshua Summers
### Figure 45: State of Manufacturing Quality Interview Transcript

<table>
<thead>
<tr>
<th>Interview Type</th>
<th>Check Outs</th>
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</thead>
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<tr>
<td>In Conference</td>
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<td>Role</td>
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<table>
<thead>
<tr>
<th>Key Points</th>
<th>Details of the Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. [21] what equipment can be automated?</td>
<td>The interviewee explained that the organization utilizes bar code scanners for automation. The system being utilized involves quality records of parts per operation, in-process and post-process inspections. Quality scores are tracked by the automated system using embedded sensors and cameras. The operator's performance is monitored through real-time data collection. Issues are reported through a dedicated system. Maintenance tasks are performed by a team of skilled technicians who work closely with the assembly line.</td>
</tr>
<tr>
<td>2. [15] how testing is conducted?</td>
<td>The interviewer asked about the testing procedures. The assembly line follows a rigorous testing protocol. Each assembly is subjected to multiple inspections before being passed along to the next stage. The testing methods are standardized to ensure consistency and reliability.</td>
</tr>
<tr>
<td>3. [10] training of operators?</td>
<td>The company places a strong emphasis on operator training. New employees undergo extensive training before being allowed to work on the assembly line. The training program includes both classroom sessions and hands-on practice. Additional training is provided to existing employees as needed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Notes</th>
<th>Impact on Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quality scores have a direct impact on the workflow.</td>
<td></td>
</tr>
<tr>
<td>2. Quality standards are rigorously enforced within the organization.</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Highest</th>
<th>New Goals</th>
</tr>
</thead>
</table>

Each image in the document represents a different aspect of the manufacturing quality interview, focusing on equipment, testing, training, and the overall impact on the manufacturing process.
Bibliography


[21] Francesca Beddie, Mette Creaser, Jo Hargreaves, and Adrian Ong. Readiness to meet demand for skills: a study of five growth industries. 2014.


