

## **Exploring Teamwork Experiences in Collaborative Undergraduate Research (REU) Programs through Tuckman's Group Development Theory**

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## Abstract

**Background:** Undergraduate Research Programs (URPs) provide students with opportunities to engage in authentic research experiences under the mentorship of faculty members. URPs are increasingly recognized as an important component of undergraduate education, as they can help students develop critical thinking skills, research skills, and teamwork skills. A notable initiative in this regard is the Research Experiences for Undergraduates (REU) funded by the National Science Foundation (NSF) which highlights the importance of such programs in science, engineering, and mathematics. Effective teamwork is essential for success in URPs, as students often work together to design and conduct experiments, analyze data, and write research papers. Effective teamwork can also help students to learn from each other and to support each other through the challenges of research.

**Purpose:** The purpose of this study is to examine the experiences of undergraduate students regarding teamwork in a collaborative REU program using Tuckman's Group Development Theory. The central research question guiding this study is: *"How do undergraduate students experience and manage teamwork in collaborative research settings?"* The study aims to identify the strengths and challenges of teamwork in URPs, as well as the methods and processes that students use to manage teamwork effectively.

**Methods:** The study was conducted in a 10-week summer, full time, onsite REU program at a large Midwestern University. Fourteen students from all over the US worked in teams on a variety of research projects in the fields of engineering and applied energy at the host university. At the end of the program, the students completed a guided reflection, and the collected data was thematically analyzed to reveal perceptions about their experiences working as a team.

**Results:** Students reported diverse strengths in teamwork, such as the importance of differing perspectives and experiences, positive mentorship dynamics, and the value of adaptability and effective communication. Challenges included issues with resource management, conflict due to differing and rigid opinions, and communication barriers, especially in culturally diverse groups. Students utilized organizational tools and strategies, conducted regular meetings, and emphasized personal accountability and leadership to manage these challenges effectively.

**Implications:** The study emphasizes the need for structured protocols in URPs for managing shared resources and cultural diversity. Incorporating cultural competence training and clear conflict resolution mechanisms can enhance team collaboration. Expanding the role of mentors beyond subject matter expertise to include the facilitation of team dynamics and providing systematic mentor-mentee matching could further improve teamwork efficacy. Policies should also focus on developing interdisciplinary teams and soft skills. Encouraging engagement with URP alumni as well as the industry can provide current participants with networking opportunities, career advice, and insights into the long-term benefits of URPs. Finally, research can be demanding, therefore, providing mental health support and stress management resources for students participating in URPs can help students maintain a healthy work-life balance.

*Keywords: undergraduate research, teamwork, collaborative learning, group development theory, engineering education, URP, research program, NSF, REU, Tuckman*

## **1. Introduction**

### 1.1 Undergraduate Research Programs (URP)

Undergraduate Research Programs (URPs) have emerged as a pivotal component in higher education, significantly benefiting students, faculty, and universities alike [1], [2], [3]. These programs offer a unique combination of hands-on research experience and mentorship, enhancing students' learning and career trajectories [4]. A notable initiative in this regard is the Research Experiences for Undergraduates (REU) funded by the National Science Foundation (NSF) [5] which highlights the importance of such programs in science, engineering, and mathematics [6]. These REUs consist of ten or so undergraduates who work in the research programs of the REU host universities across the United States [7].

One of the primary benefits of URPs is their influence on students' decisions to pursue graduate degrees and careers in academia or scientific research [3]. These programs play a crucial role in shaping the future workforce in science and engineering fields. Moreover, the skills developed through these experiences, such as critical thinking, problem-solving, and teamwork, are highly transferable and valuable in various professional settings [4]. Lopatto [2] also notes the improvement in communication skills, both oral and written, which is crucial for success in both academic and industry settings.

For universities and faculty, URPs offer a platform to mentor the next generation of researchers, create a dynamic learning environment, and contribute to the broader field of study. This involvement also promotes a culture of research within the institution, fostering a more intellectually stimulating academic environment. This can help enhance a university's reputation as a center for research and learning and attract high-achieving students and faculty, thereby raising the overall academic profile of the institution. Furthermore, these programs can lead to external funding opportunities and collaborations with industry and other universities, expanding the institution's reach and impact [8]. The research conducted in these programs often leads to publications and presentations, further contributing to the scholarly community [9].

Finally, URPs contribute to student retention and success in STEM fields. Russell et al. [10] found that students who participate in undergraduate research are more likely to persist in their chosen field of study and achieve higher grades. This finding is particularly significant in STEM fields, where retention and success rates have been traditionally lower [11]. Therefore, Undergraduate Research Programs like NSF-funded REUs are invaluable in shaping the future of education and research in STEM fields. They offer a multifaceted approach to learning, combining practical research experience with academic rigor, benefiting students, faculty, and institutions alike.

## 1.2 Role of Teamwork in URPs

Teamwork is a fundamental aspect of URPs that significantly enhances the educational and developmental outcomes for students [3]. It is not only a skill to be learned; it's a process through which learning itself becomes more effective and engaging. Teamwork in educational settings fosters a collaborative learning environment which can result in higher achievement and greater productivity compared to individual efforts [12], [13]. This is particularly true in research settings, where the complexity of problems often requires diverse perspectives and skill sets. In URPs, teamwork enables students to tackle intricate research questions, pooling their individual strengths and knowledge.

The significance of teamwork in URPs extends beyond academic achievements. Michaelsen et al. [14] argue that teamwork helps students develop essential soft skills such as communication, conflict resolution, and leadership [15], [16]. These skills are crucial for career success in any field, especially in research and development sectors where teamwork is often integral to the process. Moreover, URPs provide a unique context for teamwork as they often involve interdisciplinary collaboration. This interdisciplinary nature of teamwork in URPs can lead to innovative approaches and solutions, as students learn to integrate knowledge from different fields. It also prepares students for the workforce, where interdisciplinary teams are increasingly common.

The effectiveness of teamwork in URPs, however, depends on several factors. According to Springer et al. [17], the success of collaborative learning is influenced by the nature of the task, the composition of the team, and the support provided by the institution [18]. In URPs, where the tasks are complex and interdisciplinary, carefully selecting team members and providing adequate institutional support is key to fostering effective teamwork.

## 1.3 Purpose of the Study

The overarching purpose of this study is to explore and understand the dynamics of teamwork within the context of Undergraduate Research Programs (URPs). While the importance of teamwork in enhancing learning outcomes and skill development in URPs is well-documented, there is a need for a deeper investigation into how teamwork operates within these specific educational settings. This study aims to fill this gap by examining the nature, challenges, and successes of teamwork in URPs.

The central research question guiding this study is: *"How do undergraduate students experience and manage teamwork in collaborative research settings?"* To comprehensively address the main research question, the study will explore the following sub-questions:

- *RQ1*: What are the perceived weaknesses of teamwork as experienced by students?
- *RQ2*: How do students in URPs navigate and resolve conflicts within their teams?
- *RQ3*: What are the strengths of teamwork as perceived by students in URPs?

By addressing these questions, the study aims to provide a nuanced understanding of the role and impact of teamwork in URPs. It seeks to offer insights into best practices for fostering effective teamwork in such programs and to highlight the potential areas for improvement in

team dynamics. This, in turn, can inform the design and implementation of future URPs, enhancing their efficacy in student development and research output.

## 2. Theoretical Framework

This study is grounded in the Group Development Theory, as proposed by Tuckman [19]. Group Development Theory states that teams go through specific stages of development, which include forming, storming, norming, performing, and adjourning. These stages represent the team's journey from initial formation to becoming a cohesive and effective unit, as shown in Figure 1 [20]. The theory emphasizes that understanding and managing these stages is crucial for successful team collaboration.

In the context of Undergraduate Research Programs (URPs), this theory can provide valuable insights into how teams of undergraduate students progress through these stages during their research projects. It allows us to explore the challenges and strengths associated with each stage and how students manage teamwork dynamics. For instance, during the "storming" stage, teams may experience conflict and differing opinions. Understanding this stage helps identify strategies for resolving conflicts and improving collaboration which brings teams into the "norming" stage where teams may work towards resolving these issues. Working out the conflicts would eventually lead them into "performing" stage where they experience effective teamwork dynamics and productivity.

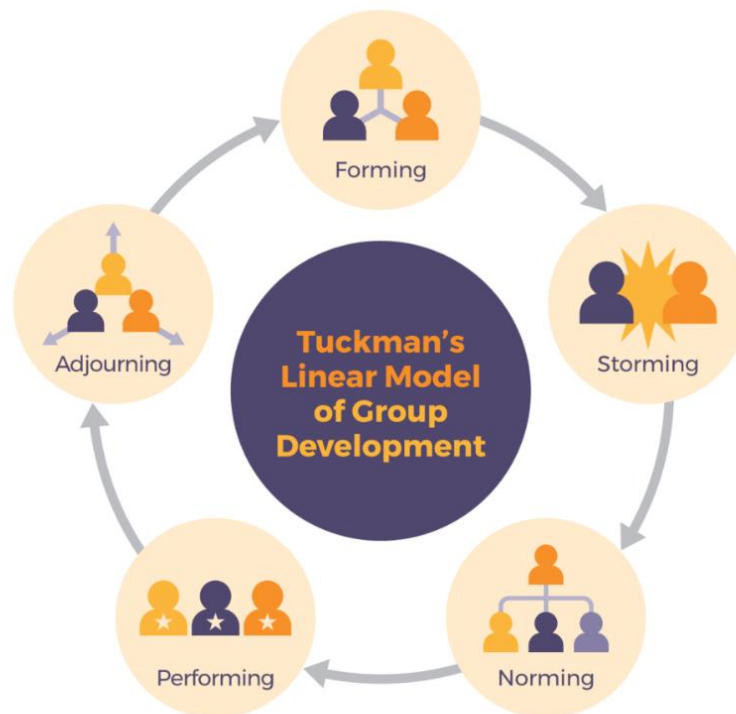


Fig 1. Stages of Tuchman's Model

Group Development Theory also highlights the importance of leadership, communication, and interpersonal skills in moving from the storming stage to the norming and performing stages. The application of Group Development Theory to teamwork in URPs is particularly relevant due to the unique nature of these programs. URPs often bring together students with diverse backgrounds, experiences, and research interests. As a result, teams in URPs may face challenges related to adapting to new perspectives, managing conflict, and establishing effective communication. By examining the experiences of students within the framework of this theory, we can better understand the factors that contribute to effective teamwork and provide recommendations for enhancing teamwork experiences in URPs.

### **3. Methods**

#### **3.1 Context & Participants**

The study was conducted in a 10-week, on-site, full-time (40 hrs. per week) summer REU program at a large, research-based Midwestern University. The participants comprised 14 engineering and engineering technology undergraduate students from various universities across the United States. Out of the 14 students, 10 identified as male and 4 identified as female. Most of the students in the course were in the third or fourth year of their college education and were pursuing majors like mechanical engineering, electrical engineering, computer engineering and industrial engineering. Of those, 29% students specified their ethnicity as White, 29% as Hispanic or Latino, 21% as Black or African American, 14% as Asian while 7% as American Indian or Alaska Native. Overall, 72% of the students belonged to URM (underrepresented minorities) aligning with the focus of the REU program [21].

These students were selected based on their interests and academic standing. The REU program aimed to provide participants with a research experience integrating the best aspects of academic applied research (e.g., theoretical basis and rigorous scholarship) with essential business practices (e.g., real-world customer discovery and developing sound business models). The participants were divided into five research groups based on their project preferences. Each group, consisting of two to three students, was led by a faculty advisor, totaling five faculty advisors for the program. The faculty advisors were provided training on mentorship best practices, inclusive teaching strategies, effective communication skills, and project management techniques to effectively deliver the REU program [22].

#### **3.2 Data Collection**

Data was collected through a guided reflection process administered via Qualtrics at the end of the program. The reflection included open-ended questions designed to elicit detailed responses about the students' experiences working in their respective teams. The questions included:

- What were the strengths you experienced working as an advisor team?
- What were the challenges you faced working as an advisor team, and how did you overcome such challenges?
- What specific methods or processes did you use to track your progress, manage time, and seek assistance?
- How did your specific methods and processes (as mentioned in previous question) help

you achieve your final project goals? Discuss any wins or shortcomings.

### 3.3 Data Analysis

The data analysis followed a thematic analysis approach, as outlined by [23], to identify patterns, themes, and meanings. This involved an iterative process of coding the data in an open-coding framework to identify key concepts and ideas. These initial codes formed the basis for the codebook, which provided a set of predefined codes to apply consistently across the dataset. Once the codebook was established, the codes were organized into potential themes by identifying patterns and recurring topics through iterative refinement (axial coding). Utilizing Tuckman's model, these emerging themes were aligned with the stages of storming, norming, and performing, directly correlating with the research questions of the study. This process, from open coding to thematic structuring, allowed for an in-depth exploration of team dynamics within the REU program.

### 3.4 Ethical and Trustworthiness Considerations

To ensure the ethical integrity of the study, informed consent was obtained from all participants. The data was anonymized to protect the identity of the participants and stored securely on Box. To enhance the trustworthiness of the findings, an additional coder was enlisted to conduct initial coding and analysis and participate in peer debriefing and inter-rater reliability (IRR) analysis. The IRR analysis measured the degree of agreement among the coders in applying the codes and identifying themes. The IRR score of 94% indicated a high level of agreement, demonstrating the consistency and reliability of the coding process. During the peer debriefing session, researchers discussed randomly selected responses to align the understanding of the text and interpretation to identify and examine any potential biases or assumptions, contributing to the rigor and validity of the analysis.

## 4. Results

### 4.1 Storming Stage (Teamwork Challenges)

This subsection relates to RQ1: What are the perceived weaknesses of teamwork as experienced by students?

*Issues with resource management:* A specific challenge that emerged was managing shared resources, which is crucial in a lab setting. “The main challenge is the management of the resource. In a research team, most of the machines are for everyone...it is inevitable that multiple students need the same machine to do their research. Managing a schedule is very important. I still do not have a clear solution for this challenge” a student recounted. Another student mentioned, “We did not experience challenges...except for one thing, I had to share the vacuum oven”.

*Conflict and rigidity in opinions:* Conflicting ideas and approaches were common challenges. A student described their struggle, “A key challenge I faced...was that my labmates and I

sometimes had conflicting ideas about assignments. With each of us coming from different backgrounds, we would often interpret the expectations of our program and advisor differently. This led to debates as we tried to agree on the best approach...it was frustrating at times” This sentiment was shared by another student who stated, “The biggest challenge we faced...was in disagreeing over the research paper and poster...We all had different opinions on how we should do it...we still wasted our time discussing them.” The resolution of these conflicts often required patience and negotiation, illustrating the complexity of teamwork in research. Another student referred to “my teammates inability to compromise or collaborate” as an unresolvable challenge.

*Cultural diversity and communication barriers:* Despite the strengths in communication, there were notable challenges too. One student mentioned "feeling like an outsider at times and effectively communicating with my team.” as a major challenge while another resonated “I struggled to ask for help, fearing that basic questions might make me seem inadequate.” This highlights the complexities of communication in culturally diverse groups that go beyond simple communication issues. More difficulties were faced in the beginning of the project that were resolved eventually – “Initial challenges faced were navigating different working styles.” and “major challenge...was establishing effective communication and teamwork, especially at the beginning...led to uncertainties regarding our research project's expectations.”

#### 4.2 Norming Stage (Management of Teamwork)

This subsection relates to RQ2: How do students in URPs navigate and resolve conflicts within their teams?

*Use of organizational tools and strategies:* Students frequently cited the use of organizational tools like detailed task lists, shared documents, personal journals and digital platforms. "used tools like calendars, checklists, and specially TODO lists to track deadlines, assign tasks, and visualize progress. This kept me organized and accountable”, a student reported, indicating the value of these tools in maintaining team coordination and focus. The use of digital platforms for communication and organization was a common theme with students leveraging platforms like Google Classroom, Outlook/Google Calendar, Apple Notes, iMessage and email for efficient communication and task management, illustrating the integration of technology in facilitating teamwork.

*Conducting regular meetings and check-ins:* Another key strategy was holding regular team meetings. “Holding regular team meetings to discuss progress, challenges, and upcoming tasks... ensures everyone is on the same page and can address any issues promptly” shared a student, highlighting the role of continuous engagement in keeping the team aligned. Another student stated, “We would check in frequently to ensure we were all on track. This peer support kept me focused.”

*Personal accountability and leadership:* Instances of students taking the lead in certain aspects of the project work or in resolving team conflicts were noted. This reflects a more active and personal involvement in the management of teamwork. A student reflected, "As the most experienced in research and academic writing, I played a leadership role in tasks like the



literature review, poster, and conference paper." Another student noted, "The main thing that kept us on track was shared accountability with my teammate group...Knowing we were interdependent, I made sure to finish my tasks so I didn't let the team down."

#### 4.3 Performing Stage (Teamwork Strengths)

This subsection relates to RQ3: What are the strengths of teamwork as perceived by students in URPs?

*Appreciation for diverse perspectives:* A recurring theme was the benefit of having diverse perspectives and interdisciplinary learning. One student reflected, "A major asset...was having members with complementary skill sets and experience levels. My teammates brought diverse talents spanning technical writing, hands-on work, programming, and more. This allowed each of us to take on roles aligned with our capabilities and learn from each other's expertise. I benefited greatly from collaborating with peers who could fill my gaps and enhance my strengths". Another student captured the essence of interdisciplinary learning: "I really enjoy having research in a team... I can also see more different research fields closely because different students may have a different research focus." These comments illustrate the richness of learning and innovation that arises from a mixture of diverse viewpoints and experiences.

*Positive mentorship dynamics:* The role of mentors in shaping the team experience was a unique aspect. Reflecting on the impact of mentorship, a student stated: "Dr. <advisor> was very kind and walked me through the measurement processes, as well as giving general advice for how to be a better researcher." while another student mentioned, "Our advisor was incredibly supportive and took the time to explain concepts to us...he encouraged us to develop our knowledge independently by providing clues rather than detailed instructions on what to do" Another student found strength in "the ability to actively listen to my advisor and value his feedback," highlighting the significance of feedback and reciprocal communication in a research setting.

*Value of adaptability and effective communication:* Many students highlighted the role of effective communication in successful teamwork. "Having teammates is a pleasure thing... I always have people to ask for assistance," shared one student, highlighting the importance of open dialogues within the team. This sentiment was echoed by another, who mentioned, "there was always a good line of communication that allowed us to get answers to our questions in a timely manner". The ability to adapt to various personalities and circumstances was frequently mentioned. A student shared, "The strengths I expressed when working in an advisory team was, being able to adapt to my teammates' personalities."

### 5. Discussion

The findings from this study provide substantial insights into the dynamics of teamwork in Undergraduate Research Programs (URPs). The study's findings align closely with Tuckman's group development theory, which says that teams go through specific stages of development. In the context of URPs, this theory sheds light on how teams of undergraduate students progress through these stages during their research projects. The richness of learning

experiences, as reported by the students, highlights the importance of cognitive diversity in fostering innovation and deeper understanding [24]. The appreciation of mentorship dynamics also reflects the importance of guidance and support in shaping effective team experiences [25], emphasizing the role of mentors not just as leaders but as facilitators of learning and collaboration. Furthermore, the adaptability and effective communication skills developed by students are in line with the findings of Felder and Brent [26], emphasizing the importance of soft skills in engineering education.

Conversely, the challenges faced by students, such as resource management and conflict resolution, reflect the complexities of real-world research environments. These findings echo the work of Johnson and Johnson [27], who identified that effective teamwork is often hindered by resource constraints and interpersonal conflicts. Similarly, the rigidity in opinions and difficulties in conflict resolution are reflective of the challenges in negotiating diverse viewpoints, a skill essential in today's interdisciplinary research environments [28]. The study offers novel insights into the role of cultural diversity and communication barriers in teamwork within URPs. The complexities highlighted by students regarding feeling like an outsider or struggling to communicate effectively suggest that while diversity brings valuable perspectives, it also introduces challenges that require careful navigation [29]. This emphasizes the need for URPs to include cultural competence training and support structures to facilitate effective communication and collaboration in diverse teams.

The use of organizational tools and regular meetings, as reported by the students, reflects the importance of structured approaches to teamwork management. This aligns with the findings of Hülshager et al. [30], who found that clear communication channels and structured processes are critical for effective team functioning. Additionally, the instances of personal accountability and leadership align with the findings of Salas et al. [31] and Boud et al. [32], who emphasized the role of shared leadership and mutual accountability in high-performing teams, suggesting that active engagement in team roles enhances learning outcomes.

The study's findings also resonate with Kolb's Experiential Learning Theory (ELT) [33], emphasizing learning as a transformative process where experiences are converted into knowledge. The interplay of concrete experiences and reflective observation was evident in students' accounts of adapting to diverse teamwork dynamics and utilizing feedback from mentors and peers. Abstract conceptualization was reflected in students' development of new strategies to manage team challenges, and active experimentation was seen in the application of these strategies to their research work.

## **6. Implications and Recommendations**

To optimize the effectiveness of Undergraduate Research Programs (URPs), it is crucial to implement structured protocols for managing shared resources. This should include a transparent and fair scheduling system, along with policies that ensure equitable access for all team members. Given the challenges of cultural diversity and communication barriers, URPs should incorporate cultural competence training for students and mentors to facilitate effective communication and collaboration in diverse teams. Additionally, URPs should establish clear conflict resolution mechanisms to help teams navigate differences in opinions and approaches,

possibly through workshops or mentor-led discussions. These sessions should focus on developing students' skills in negotiation, empathy, and problem-solving within a team context. Additionally, the role of mentors should be expanded beyond subject matter expertise to include the facilitation of team dynamics. Training mentors in effective communication strategies and inclusive practices will contribute significantly to a supportive and productive research environment. This training can help mentors identify and address potential team issues proactively, fostering a more cohesive and efficient team.

Policies governing URPs should promote the formation of interdisciplinary teams. By bringing together students from different academic backgrounds, URPs can stimulate creative approaches to research challenges. Regular assessments and feedback mechanisms are vital to identify and address any issues promptly. Furthermore, policy guidelines should emphasize the development of soft skills such as leadership, teamwork, and communication as integral outcomes of URPs. Recognizing these skills as essential competencies in STEM education will encourage a more holistic approach to student development.

It is recommended to implement a more systematic mentor-mentee matching process, considering both research interests and interpersonal dynamics. This can improve the quality of mentorship and enhance the overall research experience. Encouraging engagement with URP alumni to provide current participants with networking opportunities, career advice, and insights into the long-term benefits of URPs. Partnerships with industry and other academic institutions can provide students with broader perspectives, access to diverse resources, and real-world applications of their research. Research can be demanding, therefore, providing mental health support and stress management resources for students participating in URPs can help students maintain a healthy work-life balance. Finally, integrating topics of sustainability and social responsibility into URPs can encourage students to consider the broader impact of their research on society and the environment.

## **7. Conclusion, Limitations, and Future Work**

The findings of this study offer important insights into the dynamics of teamwork in URPs, affirming the benefits of diverse perspectives, mentorship, and adaptability, while also acknowledging the challenges of resource management, conflict resolution, and cultural diversity. These insights not only contribute to the understanding of teamwork in undergraduate research but also provide a valuable reference for enhancing the design and implementation of such programs.

While the study provides valuable insights, it has certain limitations. The study focused on a single URP at a Midwestern University, potentially limiting the generalizability of the findings to other geographical and institutional contexts. Additionally, the study relies on self-reported reflections which might introduce biases or inaccuracies in representing teamwork experiences. Future research should consider exploring teamwork dynamics in diverse URPs across different geographical and disciplinary contexts to generalize the findings as well as compare teamwork experiences across various URPs to understand the impact of different institutional cultures and program structures. Additionally, longitudinal studies could offer a deeper understanding of how teamwork skills developed in URPs impact students' professional careers.

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