EFFECTS OF FUNCTIONAL ROLES ON TEAMWORK QUALITY AND PERFORMANCE IN DIGITAL FABRICATION EDUCATION

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ABSTRACT
Digital fabrication projects in FabLabs or Makerspace environments often involve complex challenges that reflect real-world situations, demanding that students manage both technical and interpersonal dynamics. The interdisciplinary nature of these projects requires the collaboration of various functional roles, with each team member contributing unique perspectives and expertise to the team effort. This study investigates the effects of functional roles on teamwork quality and performance in digital fabrication education. In FabLabs, where cross-functional collaboration is essential, understanding how different roles influence teamwork dynamics is crucial. This research examines data from 76 students in 19 groups, each assuming one of four roles: manager, designer, programmer, or prototyper. The results indicate that while designers and programmers reported slightly higher levels across most teamwork quality dimensions, there were no significant differences between roles across teamwork dimensions. Strong positive correlations were found between teamwork quality, team member success, and team performance. Notably, cohesion emerged as the most significant predictor of team member success, whereas the balance of member contribution was the strongest predictor of overall team performance. These findings provide valuable insights for makerspace educators, highlighting the importance of role-specific interventions and integrated teamwork training in design education to enhance collaboration and innovation in digital fabrication environments.

Keywords: Teamwork quality, FabLab, team performance, team roles, design education

1 INTRODUCTION
Digital fabrication environments, such as FabLabs and Makerspaces, have become vital learning environments for modern design education. They provide students with hands-on experience using advanced technologies like 3D printing, laser cutting, and computer-aided design (CAD), enabling them to transform digital designs into physical objects. Additionally, these environments also promote collaborative problem-solving skills [1,2]. The dynamic nature of FabLab spaces fosters innovation through the interaction of diverse skill sets and roles, making effective teamwork a crucial factor in successful prototype development. In educational settings, the tools available in FabLabs offer students the opportunity to materialise their ideas, thus fostering creativity and innovation [1,2].
The concept of functional roles within teams is well-established, but its application in digital fabrication education requires further examination. Functional roles refer to the specific responsibilities and tasks assigned to team members based on their skills, expertise, or project requirements. In digital fabrication projects, these roles might include designers, programmers, prototypers, and project managers, with each member contributing unique skills to the overall team effort [3].
Teamwork quality is a multidimensional construct that includes such as communication, coordination, mutual support (e.g., [4]). It plays a crucial role in the success of collaborative projects. In FabLab education, where teams are required to address both technical challenges and creative processes, the quality of teamwork can have a significant effect on learning outcomes and project results [3].
Despite the recognised importance of teamwork quality in collaborative environments (e.g., [3]), there is limited research on how different functional roles influence perceptions of teamwork quality and

overall team performance in FabLabs, where cross-functional collaboration is critical. This study aims to address this gap by investigating the influence of specific team roles on perceptions of teamwork quality, individual team member success, and overall team performance in designing and building tangible artefacts within FabLabs.

The primary objective of this research is to explore the quality of teamwork from a role-specific perspective, highlighting how different roles within FabLabs contribute to collaboration and impact team outcomes. The findings have significant implications for educators and facilitators in makerspaces, as they can help optimise collaboration in digital fabrication education.

2 BACKGROUNDS

2.1 Digital Fabrication in Education

Digital fabrication environments, such as FabLabs and Makerspaces, have emerged as important components of modern design education. They offer students immersive experiences with cutting-edge technologies and collaborative problem-solving skills. These educational spaces serve as centres/hubs for innovation, fostering the interaction of diverse skill sets and roles. As Blikstein [5] notes, digital fabrication in education provides a unique platform for constructionist learning, allowing students to engage in the creation of tangible artefacts while developing critical thinking and problem-solving skills. The integration of digital fabrication into educational curricula has been shown to enhance student learning and engagement, foster teamwork and interdisciplinary skills, and increase innovation ability [2,3]. According to Gershenfeld [6], FabLabs democratise access to tools for invention, enabling students to move from consumers to creators of technology. This shift aligns with the growing emphasis on developing 21st-century skills, including effective communication, collaboration, and digital literacy.

2.2 Teamwork Quality and Functional Roles

Teamwork quality (TWQ) encompasses a multifaceted array of dimensions, including communication, coordination, mutual support, effort, cohesion, and balance of member contribution. High-quality teamwork is instrumental in cultivating shared understanding, facilitating effective problem-solving, and generating synergy among team members. These elements are particularly important in the context of makerspaces, where the convergence of creativity, technical skills, and collaborative spirit drives innovation and productivity.

The concept of functional roles within teams has been extensively studied, with various taxonomies proposed over the years. Mathieu et al. [7] introduced the Team Role Experience and Orientation (TREO) framework, which includes six roles: organiser, doer, challenger, innovator, team builder, and connector. These roles contribute uniquely to team dynamics and performance, highlighting the importance of role balance in effective teamwork.

Research has shown that when teams are able to coherently play certain functional team roles, conflict is better managed and higher performance is achieved (e.g., [8]). Studies have indicated that the performance of tasks and social team roles is negatively related to task and relationship conflict, while being positively associated with team performance [8,9]. In the context of digital fabrication education, the interdisciplinary nature of projects necessitates the integration of various functional roles, each contributing unique perspectives and expertise to the team effort [2,3,10].

Despite the recognised importance of teamwork quality in collaborative environments, there is a notable gap in research examining how different functional roles affect perceptions of teamwork quality, particularly within FabLabs. This gap presents an opportunity for further investigation into the dynamics of teamwork in digital fabrication education, with potential implications for enhancing collaborative learning experiences and preparing students for the challenges of a rapidly evolving technological landscape.

3 METHODOLOGIES

This study employed a quantitative research design to investigate how functional roles impact teamwork quality and performance in digital fabrication education. The research was conducted within the context of a digital fabrication course involving 76 students, who were organised into 19 groups of 4 members in each group. A background questionnaire was utilised to allocate expertise equally among the teams (see Figure 1). Data was collected from these students, each selecting one of four designated roles—manager, designer, programmer, or prototyper—based on their preferences.

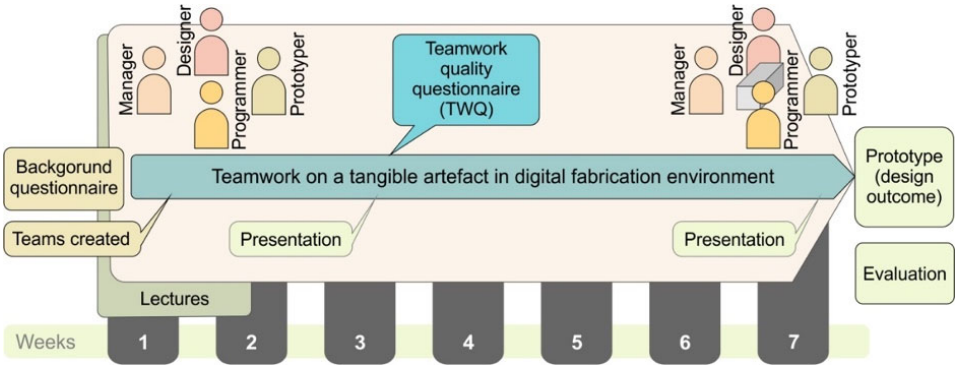

Figure 1. The digital fabrication course context, including team roles and data collection

The questionnaire [4] was adopted for the data collection and included items that measure various aspects of teamwork quality, such as communication, coordination, balance of member contributions, mutual support, cohesion, and effort. It also assessed team performance in terms of effectiveness and efficiency, as well as team members' success in relation to work satisfaction, knowledge and skill development. Students responded to the 61 items in the questionnaire on a scale from 1 (strongly disagree) to 5 (strongly agree), administered at the mid-term of the course. The research investigated three main questions:

1. How do perceptions of teamwork quality dimensions vary by role?
2. What is the relationship between teamwork quality and team outcomes, such as success and performance?
3. Which dimensions of teamwork quality are the most effective predictors of positive team outcomes in FabLabs?

To address these questions, the study utilised various statistical tests. A series of one-way ANOVA was performed to identify differences in mean scores for teamwork quality dimensions based on roles. Additionally, Pearson correlation analysis was conducted to explore the relationships between teamwork quality, team member success, and overall team performance. Multiple Regression analyses were performed to identify the most significant predictors of team member success and team performance across various roles.

4 RESULTS

To assess the scale's internal consistency, Cronbach's alpha was calculated. The analysis showed a Cronbach's alpha of 0.976 for the 61-item scale, indicating excellent reliability. Additionally, the Cronbach's alpha calculated based on standardised items was 0.978, suggesting that the items exhibit similar variances and that standardisation does not significantly affect the reliability estimate. The results are presented in the following subsections.

4.1 Role-based Differences in Teamwork Quality

To address the first research question, a series of one-way ANOVA was conducted to examine how perceptions of teamwork quality dimensions differed by role. The analysis revealed that programmers, followed closely by designers, reported slightly higher levels of several teamwork quality dimensions compared to other roles. Specifically, programmers reported higher levels of communication ($M = 4.2$, $SD = 0.2$) than designers ($M = 4.0$, $SD = 0.5$), as well as coordination ($M = 4.0$, $SD = 0.6$ vs. $M = 4.0$, $SD = 0.5$), mutual support ($M = 4.4$, $SD = 0.6$ vs. $M = 4.3$, $SD = 0.6$), effort ($M = 4.1$, $SD = 0.8$ vs. $M = 3.9$, $SD = 0.8$), and cohesion ($M = 4.1$, $SD = 0.6$ vs. $M = 4.0$, $SD = 0.6$). This trend may be due to the nature of their positions, which often require significant interaction and collaboration within the team. Notably, designers ($M = 4.3$, $SD = 0.6$) perceived a more equitable distribution of workload, as they reported a higher balance of member contribution than programmers ($M = 4.2$, $SD = 0.7$) and other roles. However, it is essential to understand that, despite these observed trends, the differences between individual roles across all teamwork dimensions were not statistically significant ($p > .05$). The mean scores across all roles ranged from 3.2 to 4.4 on a 5-point Likert scale, indicating generally positive perceptions of teamwork quality.

4.2 Relationship Between Teamwork Quality and Team Outcomes

Pearson correlation analyses were conducted to examine the relationships between teamwork quality, team members' success, and team performance to investigate the second research question. A strong positive correlation was found between overall teamwork quality and team member success ($r = 0.831$, $n = 76$, $p < 0.001$). This result indicates that higher perceptions of teamwork quality were associated with greater individual success and satisfaction among team members. Similarly, a strong positive correlation was observed between teamwork quality and team performance ($r = 0.804$, $n = 76$, $p < 0.001$). Teams that reported higher levels of teamwork quality tended to achieve better performance outcomes in their digital fabrication projects. All dimensions of teamwork quality were positively correlated with each other, with correlation coefficients ranging from 0.56 to 0.80 (all $p < 0.01$). This finding suggests that improvements in one aspect of teamwork quality may have positive effects on other dimensions (see Table 1).

4.3 Predictors of Team Outcomes

To address the third research question, multiple regression analyses were conducted to identify the most effective predictors of team member success and team performance. A multiple regression model with all teamwork quality dimensions as predictors explained 70.6% of the variance in team member success ($R^2 = 0.706$, $F_{(6, 69)} = 27.626$, $p < 0.001$). Cohesion emerged as the strongest predictor ($\beta = 0.332$, $p = 0.010$), followed by coordination ($\beta = 0.178$, $p = 0.081$). For team performance, the regression model accounted for 65.7% of the variance ($R^2 = 0.657$, $F_{(6, 69)} = 21.990$, $p < 0.001$). Balance of member contribution was the most significant predictor ($\beta = 0.196$, $p = 0.044$), with coordination ($\beta = 0.208$, $p = 0.063$) and cohesion ($\beta = 0.261$, $p = 0.061$) also contributing meaningfully to the model.

Table 1. Pearson Correlation Coefficients among Teamwork Quality (TWQ) Dimensions

Dimension	1	2	3	4	5	6
1. Communication	-					
2. Coordination	0.691** (<.001)	-				
3. Mutual Support	0.754** (<.001)	0.688** (<.001)	-			
4. Effort	0.743** (<.001)	0.713** (<.001)	0.748** (<.001)	-		
5. Cohesion	0.789** (<.001)	0.676** (<.001)	0.764** (<.001)	0.803** (<.001)	-	
6. Balance of Member Contribution	0.565** (<.001)	0.621** (.062)	0.656** (.076)	0.655** (<.009)	0.646** (<.002)	-

**. Correlation is significant at the 0.01 level (2-tailed).

5 DISCUSSIONS

5.1 Role-based Perceptions of Teamwork Quality

The findings indicate that designers and programmers generally reported slightly higher levels of teamwork quality across various dimensions compared to other roles. This trend, although not statistically significant, suggests that these roles may naturally facilitate more interaction and collaboration within the team. For instance, Kleinsmann and Valkenburg [11] found that designers often play a central role in facilitating communication and coordination in multidisciplinary design teams. However, the absence of significant differences between individual roles across teamwork dimensions suggests that all roles contribute equally necessary to the overall success of the team. This finding supports the work of Mathieu et al., who emphasised the importance of balanced team composition in their TREO framework [7].

5.2 Relationship Between Teamwork Quality and Outcomes

The strong correlation between the quality of teamwork, the success of individual team members, and overall team performance emphasises the importance of effective collaboration in digital fabrication education. This relationship aligns with the findings of Hoegl and Gemuenden, who demonstrated that

high-quality teamwork is significantly linked to better team performance in innovative projects [12]. These results highlight the need for educators, in particular makerspace instructors, to prioritise teamwork skills alongside technical competencies, as suggested by Blikstein [5] in their work on digital fabrication in education.

5.3 Predictors of Team Success and Performance

Results indicated that cohesion and balance of member contribution are key predictors of success and performance. The significance of cohesion aligns with Chiocchio and Essiembre's meta-analysis, which found that cohesion is the strongest predictor of team effectiveness in academic settings [13]. This highlights the importance of fostering social bonds and shared identity in student teams. The predictive power of the balance of member contribution aligns with the findings of Liden et al. [14], who argue that perceived equity mitigates social loafing and enhances engagement. However, coordination's borderline significance ($p = 0.063$ for team performance) suggests that while task alignment matters, its impact may be secondary to socio-emotional factors like cohesion. Makerspace educators should prioritise strategies that simultaneously strengthen interpersonal bonds and clarify role expectations.

6 IMPLICATIONS FOR EDUCATION AND PRACTICE

These findings have several practical implications for design education and makerspace management. First, it is essential to integrate a role-aware teamwork approach into design education, as suggested by Rodriguez et al. in their study on collaborative learning in architectural education [15]. While roles such as designer and programmer naturally encourage collaboration, structured training in role-specific communication could further enhance coordination [12]. Second, Makerspace or FabLab educators should develop targeted interventions to enhance specific teamwork quality dimensions, particularly the balance of member contribution and cohesion. It is recommended that team-building activities that promote cohesion, such as peer reflection exercises [16], be implemented, and tools for workload transparency, like shared task boards, be utilised to improve perceptions of equity of team effort. Third, when composing teams for digital fabrication projects, it is important to consider the balance of roles and the potential for role-specific contributions to teamwork quality, as recommended by Mathieu et al. in their TREO framework [7]. Fourth, it is important to align grading rubrics with teamwork quality metrics (e.g., mutual support and coordination) to incentivise collaborative behaviours [8]. Lastly, by addressing role-based teamwork needs, educators and instructors can optimise collaboration, innovation, and satisfaction in digital fabrication environments, ultimately enhancing both individual and team success. This aligns with the goals of 21st-century skills development in education [17].

6.1 Limitations and Future Research

This study offers valuable findings; however, it is limited by its focus on just one digital fabrication course with a relatively moderate sample size of 76 students across 19 groups. Future research could examine these dynamics in multiple educational settings and over extended periods to improve the generalisability of the findings. Additionally, investigating the long-term effects of role-aware teamwork training on student outcomes, as well as how these findings apply to professional environments in technology-driven fields, would further improve our understanding of effective collaboration in digital fabrication contexts.

7 CONCLUSIONS

This research provides valuable insights into the dynamics of teamwork quality in project-based learning, emphasising the crucial role of effective collaboration for both individual and team success in digital fabrication education. While there were slight variations in teamwork perceptions based on functional roles, with designers and programmers reporting marginally higher scores, the lack of statistically significant differences indicates that quality team processes go beyond specific role assignments. The strong predictive relationship between the dimensions of teamwork quality and educational outcomes highlights the potential for targeted interventions to significantly improve learning effectiveness. Notably, cohesion emerged as the primary predictor of team member success, while the balance of member contribution was identified as key to overall team performance. These findings suggest a clear direction for educational practice. Instructors should adopt strategies that simultaneously strengthen interpersonal bonds while ensuring equitable participation among team members. As the field

of digital fabrication education continues to evolve, these findings can inform curriculum design, team formation strategies, and assessment methods.

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