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Believing the Results: Validation of the Tuckman Team Development Questionnaire for Use with Engineering Student Design Teams

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Believing the Results: Validation of the Tuckman Team Development Questionnaire for Use with Engineering Student Design Teams

This full research paper discusses the validation of the Tuckman Team Development Questionnaire for use in the context of first-year engineering teamwork. The Tuckman Questionnaire was originally developed to measure perceptions of team dynamics as a continuously evolving process over the life of the team. The Tuckman framework contains four stages of team development: Forming, Storming, Norming, and Performing. Although engineering educators have used this questionnaire with engineering student design teams, there was little or no evidence found in the literature attesting to its validity or reliability. Since validation of a questionnaire is important if the results are to be accepted as accurate and useful, we provide initial validity evidence of this measure through this study. The research question of this paper is as follows: Can the Tuckman team development questionnaire be considered valid and reliable for use with engineering student design teams?

The questionnaire contains 32 items, with eight items corresponding to each of the four development stages. The items were listed randomly to mitigate response bias. Participants completed the questionnaire as part of an assignment during the twelfth week of an introductory engineering design course, in which one of the learning objectives was the ability to work effectively on a team to complete a semester-long design project. Data were collected from approximately 90 participants in each of two fall semesters and 50 participants in each of two spring semesters, for a total of nearly 280 sets of responses. Study variables were the four Tuckman team development stages.

The questionnaire was administered at the 75% completion point of the semester, where it was expected that the teams would have approached the Performing stage, or were between Norming and Performing. The questionnaire results revealed that student teams were operating according to the Norming and/or Performing stages, which could be an indication of face and content validity in terms of consistent results for several cohorts of student teams over time. However, the issue remains as to whether the questionnaire is actually valid and reliable. Using the data that we collected, we examined Cronbach's alpha to check the reliability of the questionnaire and conducted exploratory factor analysis.

This study contributes to the field of engineering education by providing initial validity and reliability evidence for the Tuckman Team Development Questionnaire, in the context of first-year engineering courses. First year engineering students are often inexperienced at functioning well on a team and are sometimes motivated by personal agendas to the detriment of team welfare. A valid team development questionnaire would inform instructors as to how they should guide a team that is struggling with interpersonal conflict and/or difficulty in completing project work cooperatively.

Background

It is widely agreed that the ability to function productively on a team is an important engineering skill [1]. This ability is also a common learning outcome in project-based introductory engineering courses [2]. Quite often, student teams are not self-selected, in order to simulate similar situations in the engineering workplace, and to prompt students to develop additional flexibility and objectivity toward fellow team members' diverse educational, cultural, and behavioral orientations. Since these courses and teams often last for only one semester, the amount of time to develop this ability is short, and engineering educators need valid ways to monitor effective teamwork in order to provide appropriate guidance to help their teams to be successful. Guidance by educators is also beneficial to many students who have little knowledge or experience with a successful project team, or how to understand and improve their team's dynamics in a relatively short period of time.

For these reasons, we needed a method to determine the validity and reliability of the Tuckman Team Development Questionnaire, which we used to measure individual team members' perceptions of their team's dynamics at a specific milestone in the design project [3]. Differences in perceptions of team development can lead to conflicts among members that undermine effective teamwork. We also believe that the recent pandemic severely limited our students from developing the ability to function effectively on any team, much less a non-self-selected one [1], [4], [5]. A complete listing of all of the Tuckman Questionnaire items can be found in Appendix A, along with the development stages to which they are associated.

Since the validation of a questionnaire is important if the results are to be accepted as accurate and useful, we provide initial validity evidence of this measure through this study. Therefore, the research question of this paper is as follows:

- Can the Tuckman team development questionnaire be considered valid and reliable for use with engineering student design teams?

There are multiple ways to validate a quantitative research instrument [6]. To validate the Tuckman Team Development Questionnaire used in this study, we sought to demonstrate construct validity. Construct validity is often measured by statistical methods to determine the degree of operationalization of the constructs in the survey, such as factor analysis, principal components analysis, and assessment of internal consistency (e.g., Cronbach's alpha) [7]–[9].

We found only one prior study that used factor analysis to validate a questionnaire that measured team development [10]. However, the questionnaire used in that study contained different items for each of the Tuckman stages, and a different method for scoring the items. Therefore, we thought a separate validation study for the instrument we have would be necessary.

Conceptual Framework for the Tuckman Questionnaire

The Tuckman Questionnaire was originally developed to measure perceptions of team dynamics as a continuously evolving process over the life of the team. The Tuckman framework contains four stages of team development: Forming, Storming, Norming, and Performing [3], [11]. A brief description of each stage is shown in Table I:

TABLE I

Tuckman Team Development Stages

Tuckman's Model Stage	**Key Characteristics of This Stage**
Forming	Orientation through testing: identifying boundaries for behavior; developing relationships with other team members; adherence to standards; recognizing interdependence.
Storming	Catharsis: questioning due to interpersonal issues; exhibiting emotional responses to tasks; resisting group influences.
Norming	Focus: overcoming resistance to promote cohesiveness; adopting new standards and roles; expressing opinions within mutual psychological safety.
Performing	Purposive: exert flexibility in roles to complete tasks; structure supports task completion; team energy is focused on completing tasks.

Adapted from [3], [11], [12]

Another way to view this model is through the relationships between four aspects of interpersonal interactions among team members vs. task-related activities [13]. These relationships are shown in Table II below:

TABLE II

Interpersonal Factors Related to Task Factors in Tuckman's Model

Interpersonal Interactions	***Task-Related Activities***
Testing and Dependence of/on Team Members	Recognition of Task(s)
Conflict within the Team	Emotional Responses to Task Demands
Team Cohesion Develops	Open Exchange of Interpretations
Interdependence of Roles on the Team	Emergence of Solutions to the Problem(s)

Adapted from [13]

Although the original model contained the four stages shown above, Tuckman added a fifth stage, "termination", to the model, which was later labeled as "adjourning" [13]. Tuckman specifically mentioned "termination" for this stage, focusing on the team members' emotions in response to the resolution or solution for a mission, charge, or problem. This stage appeared to be more applicable to organizational teams than to student teams, because organizational team members are more likely than students to wonder, "What's next for me?" [14]. However, a sense of exhilaration at the completion of the team's work may arise for either type of team instead [14].

The 32-item Tuckman Team Development Questionnaire used in our study did not contain items relating to the Adjourning stage [14]. Neither did another 13-item questionnaire based on the Tuckman model [15]. Since many student teams adjourn at the end of a course or semester without follow-up, it would be more difficult to collect the data to ascertain the nature of their Adjourning stage.

Research Methods

Students in a Foundations of Engineering course were required to complete the Tuckman Questionnaire as a class assignment towards the end of their respective term. Previous studies suggested that the difference between online vs. in-person course delivery did not have a significant impact on the ability of student teams to transition through different stages of teamwork development as a result of their class experience [12], [16]. For that reason, and with the aim of collecting a data set large enough for validation purposes, data from both terms were consolidated.

A first review of the Tuckman Questionnaire reveals some items worded in a negative sense, suggesting a potential need to reverse scoring scales. However, since the questionnaire is precisely intended to detect characteristics or behaviors that would position teams at a certain stage, including dysfunctional characteristics, higher scores in these negatively-worded items signal higher probability that a team is experiencing a stage where negative issues are expected. For instance, item 9: "*We generate lots of ideas, but we do not use many because we fail to listen to them and reject them without fully understanding them*" is associated with the Storming stage, and therefore higher scores for this item indicate that the team might be experiencing this stage. Therefore, the data was processed as collected.

Data processing was done in three steps: first, data were cleaned and consolidated, resulting in 286 usable data entries (i.e., complete and valid entries for different individual students). Secondly, values of Cronbach's Alpha and correlations were calculated for the instrument as a whole and for the groups of items that each stage comprises (eight items per stage). Finally, exploratory factor analysis was carried out and the results compared with the theoretical structure of the questionnaire (i.e., the four stages).

Results

Reliability

To test the reliability of the Tuckman questionnaire, we calculated Cronbach's alpha (CA) for each individual stage and the instrument as a whole, as presented in Table III. The Forming and Storming stages had a low CA which falls under 'Less Reliable' according to the levels shown in

Table IV [17]. However, at the later stages of the team development the level of reliability increases with Norming at 0.45 and Performing at 0.73. The overall CA for the Tuckman's questionnaire was 0.60, which falls in the 'Quite Reliable' level of reliability.

TABLE III

Cronbach's Alpha Values for the Entire Questionnaire

Tuckman's Model Stage	Cronbach's Alpha (Each Stage)	Cronbach's Alpha (Overall)
Forming	0.15	0.60
Storming	0.15	
Norming	0.45	
Performing	0.73	

TABLE IV

Cronbach's Alpha Reliability scale

Cronbach's Alpha Score	Level of Reliability
0.0 - 0.20	Less Reliable
> 0.20 - 0.40	Rather Reliable
> 0.40 - 0.60	Quite Reliable
> 0.60 - 0.80	Reliable
> 0.80 - 1.00	Very Reliable

Adapted from [17]

In the next step of our analysis, we calculated the correlation matrix between the items in Tuckman's questionnaire, focusing on the eight items each stage comprises. The outcome of the correlation matrix for the four stages are shown in Figure I. The color represents whether there is a positive (blue) or negative (red) correlation between items, and the intensity of the colors represent the strength of this correlation. From the outcome, we found that several items had very low correlation with other items in the same stage. Particularly, we found the following items with almost zero correlation within each stage:

Forming
Q5 Team members are afraid or do not like to ask others for help.

Storming
Q2 We are quick to get on with the task on hand and do not spend too much time in the planning

stage.
Q7 The team leader tries to keep order and contributes to the task at hand.
Q9 We have lots of ideas but don't use many as we don't listen but reject before understanding them.
Q31 There is a lot of resisting of the tasks at hand and quality improvement approaches.

Norming
Q24 The team is often tempted to go above the original scope of the project.
Q30 We often share personal problems with each other.

Performing
Q8 We do not have fixed procedures, we make them up as the task or project progresses.

These items are also highlighted in Appendix A for comparison to other items in the same development stage.

Figure I: Correlation Matrices for Each Development Stage

Top left: Forming; Bottom left: Storming; Top right: Norming; Bottom right: Performing

We removed the above-mentioned items from each of the stages and checked the corresponding reliability for each stage. After removal, the CA for each stage increased: The CA of the Forming stage increased from 0.15 to 0. 24 (“Rather Reliable”); the CA of the Storming stage increased from 0.15 to 0.51 (“Quite Reliable”); the CA of the Norming stage increased from 0.45 to 0.59 (“Quite Reliable”); and the CA of the Performing stage increased from 0.73 to 0.81 (“Very Reliable”). Similarly, the overall CA for the questionnaire with 24 items increased from 0.60 to 0.67 (“Reliable”). Table V shows the improved CA values for each stage after removing the items mentioned.

TABLE V

Revised Cronbach’s Alpha Values for Reduced Questionnaire

Tuckman’s Model Stage	**Cronbach’s Alpha (Each Stage)**	**Cronbach’s Alpha (Set of 24 Items)**
Forming (removing Q5)	0.24	0.67
Storming (removing Q2,7,9,31)	0.51	
Norming (removing Q24,30)	0.59	
Performing (removing Q8)	0.81	

Exploratory Factor Analysis

With the subset of 24 items containing increased reliability, we carried out several statistical tests to find out whether Exploratory Factor Analysis (EFA) was appropriate. Figure II shows the output of the correlation matrix for the new questionnaire, which suggests that the items within each stage are indeed correlated with each other. We used the Kaiser-Meyer-Olkin (KMO) to measure the factorability. According to Kaiser’s guidelines [15], a suggested cutoff for determining the factorability of the sample data is KMO ≥ 0.60. The total KMO was 0.84, indicating that, based on this test, we can probably conduct a factor analysis. Second, we calculated the Bartlett’s test of Sphericity and found out our p-value to be less than 0.05, which indicated that a factor analysis would be useful with the new set of data. Furthermore, we calculated the determinant, which was positive indicating that the factor analysis will probably run without issues. We used Principal Axis Factoring (PAF) instead of Principal Components Analysis (PCA) because we did not have an independent outcome for teamwork that could be predicted by the questionnaire [18].

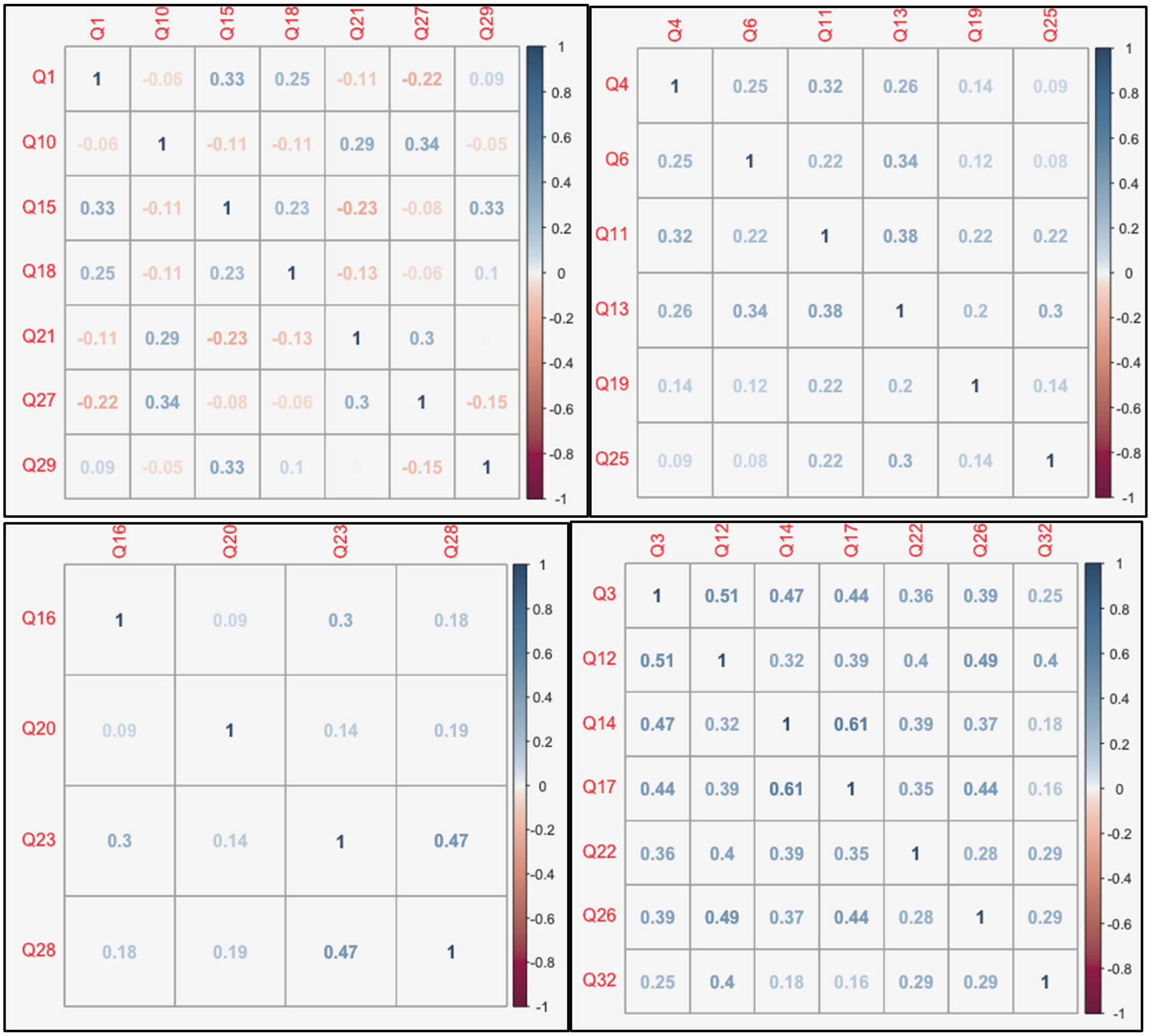

Figure II: Revised Correlation Matrices for Each Development Stage

Top left: Forming; Bottom left: Storming; Top right: Norming; Bottom right: Performing

As the first step of the EFA, we determined the number of factors. To find the number of factors to extract for the EFA, we used R's built-in *'fa'* function to create a scree plot and conduct parallel analysis. The R program also provides the maximum number of factors which should be retained, based on the scree plot output. Figure III shows the scree plot with parallel analysis results, which suggests the number of factors to be five as indicated by the green line (factors are named PA due to the PAF procedure used to extract them). Although this is one factor more than the theorized factor structure of the Tuckman questionnaire, we decided to proceed with the factor analysis with 5 factors. The outcome of the factor analysis, which includes the factor loadings, is shown in Table VI (only factor loadings larger than 0.1 are presented in the table).

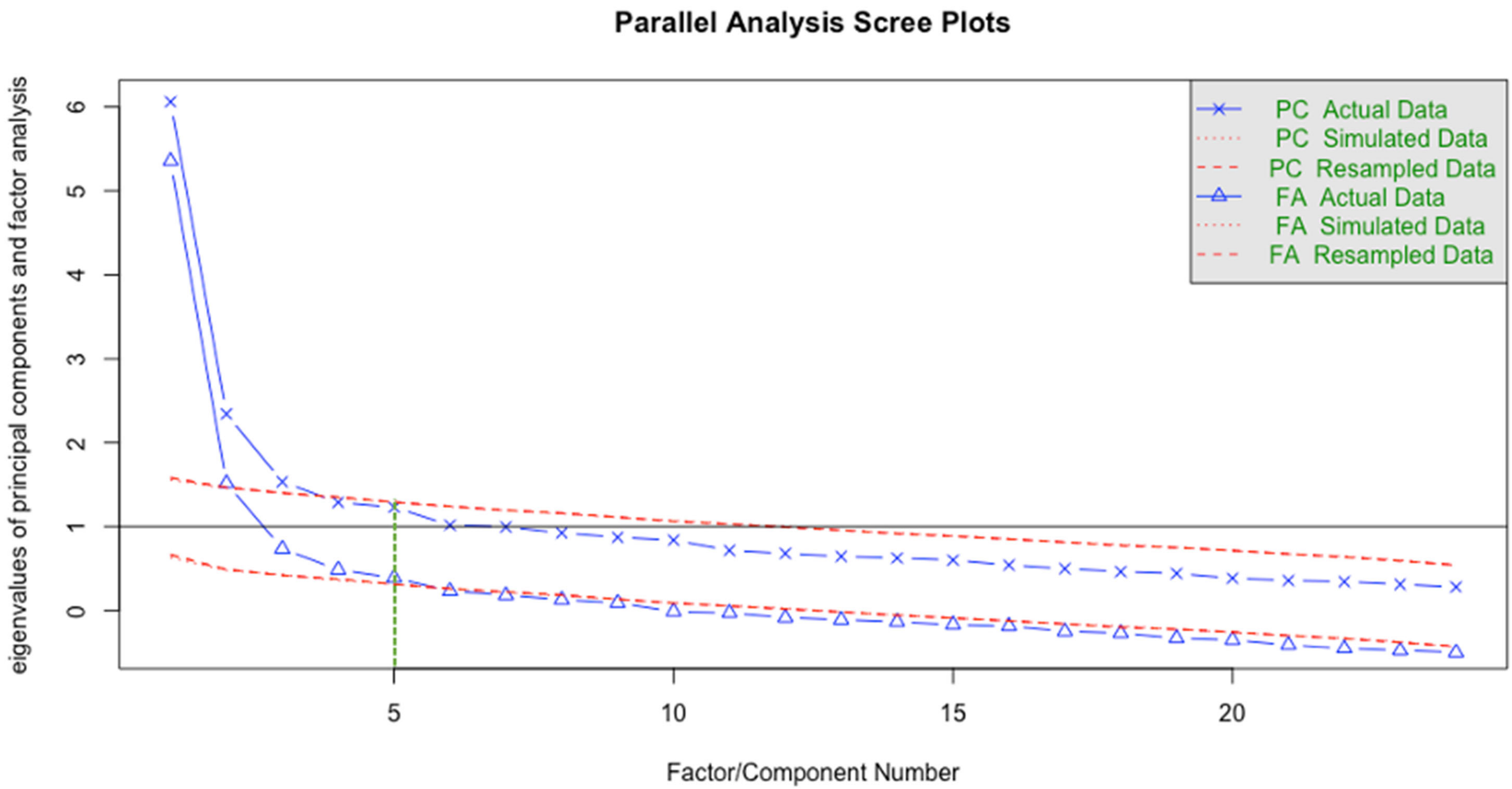

Figure III

Parallel Analysis Scree Plots

TABLE VI

EFA results summary

Items	**Factors**				
	PA1	**PA2**	**PA4**	**PA3**	**PA5**
Q12	**0.65**		0.41		
Q26	**0.62**		0.12		0.13
Q3	**0.62**	-0.19	0.14	-0.17	
Q17	**0.55**	-0.46			0.28
Q14	**0.5**	-0.44	0.11		0.35
Q13	**0.46**	-0.25	0.36		0.19
Q29	**0.42**		0.15		
Q22	**0.42**	-0.23	0.29		
Q28		**0.72**	-0.23		
Q23		**0.62**			
Q27	-0.17	**0.56**	-0.2	0.32	
Q16	-0.11	**0.38**	0.18	0.34	
Q25	0.31	**-0.34**		0.13	0.23
Q21		**0.32**	-0.28	0.3	
Q20		**0.29**			0.14
Q1	0.15	-0.12	**0.59**		0.17
Q15	0.2		**0.51**		0.15
Q6	0.11	-0.14	**0.46**		-0.2
Q11	0.31		**0.45**	0.1	0.37
Q4	0.33		**0.44**	-0.17	
Q32	0.33	0.12	**0.42**		
Q10	-0.11		-0.11	**0.79**	-0.15
Q19			0.12	-0.2	**0.55**
Q18	0.12		0.29		**0.45**

For readers' convenience, although it is not a standard practice in reporting the EFA results, we also draw a diagram that only presents each item's main factor loading and how it maps with the theorized factor (team development stage). Figure IV shows the results. The first factor found, PA1, maps to the majority of the items pertaining to the Performing stage, along with a couple of items from Forming and Norming. In particular, six out of the seven items kept from the Performing stage map directly to PA1 with loadings greater than 0.5. Similarly, three out of the four items kept for Storming map to PA2 with loadings greater than 0.4, although intertwined with a few items from Forming and Norming stages. The remaining item for Storming (Q20) has a loading of 0.28 towards PA2–the maximum value for this item across all factors–which the EFA deemed too low to suggest a definite connection. The remaining factors can not be mapped consistently to other stages. The factors PA3 and PA5 can be dropped because only one item and two items are loaded onto the PA3 and PA5 respectively.

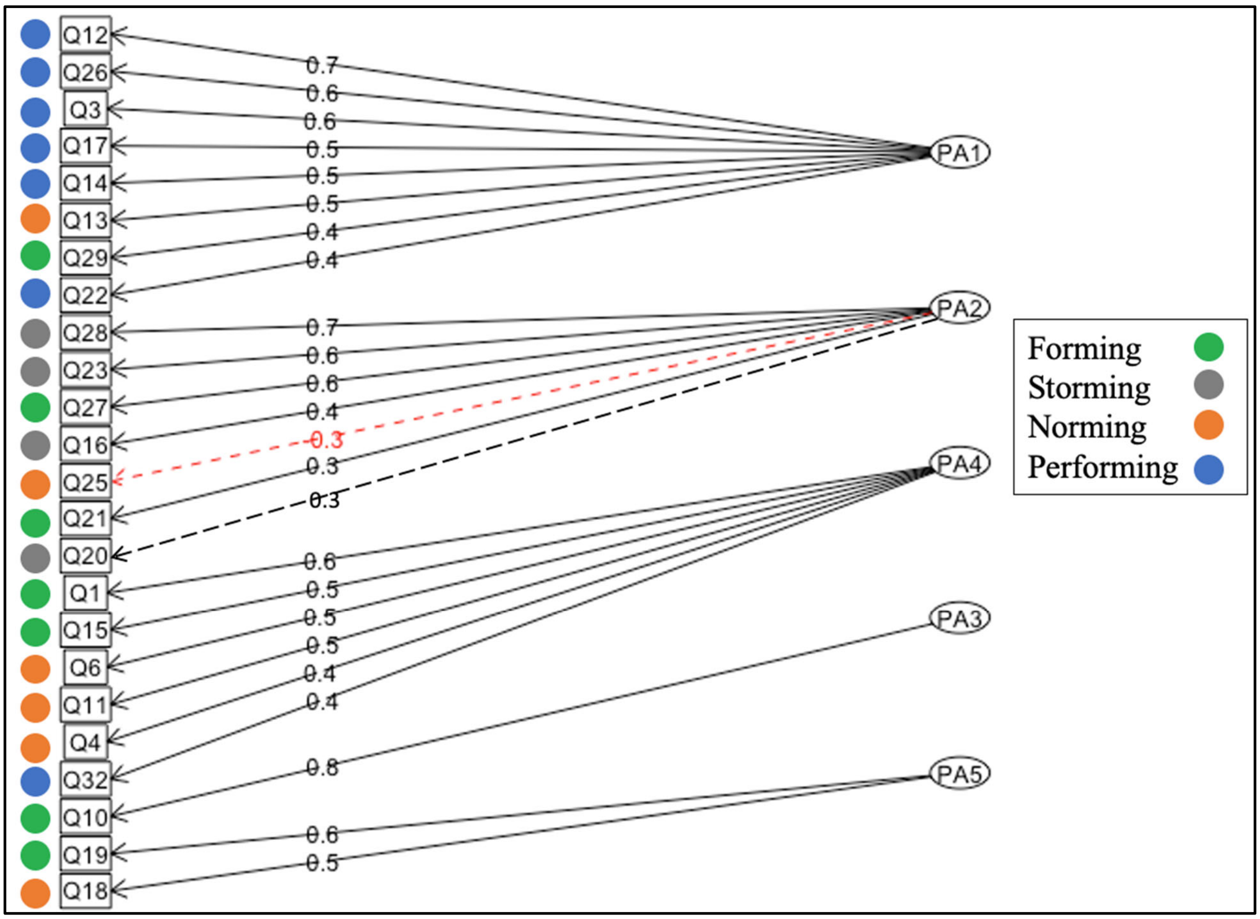

Figure IV

Factor Analysis Tree Diagram

Discussion

The Tuckman Team Development Questionnaire was not originally developed for or from the type of analysis that we conducted in this study. Its main purpose was the measurement of the perceived team development stage by each member of a team, which informs a discussion by the team about their areas of success and difficulty. That being established, the use of psychrometric tools is still useful to probe the reliability and validity of this questionnaire to use in the context of student teams in first-year engineering courses.

Our initial results exhibit consistency for questionnaire items corresponding to the Norming and Performing stages, but not for Forming or Storming. By removing items that showed very low or no correlation to other items within each stage, we saw an increase in the internal consistency of the questionnaire while maintaining at least four items per stage, which suggests that the offending items might be removed to increase the reliability of the questionnaire. Some of the items removed are worded in ways that might lead to multiple and potentially opposing interpretations, as reported informally by a number of student teams.

The factor analysis tree diagram in Figure IV shows that factor PA1 maps to all of the questionnaire items in the Performing stage, which supports the validity and reliability of the questionnaire for identifying that a team has attained the Performing development stage. Similarly, results for factor PA2 suggest that the streamlined questionnaire seems to be valid and reliable to identify teams transitioning the storming stage, especially the items Q27, Q25, Q21 are cross-loading items and can be removed. However, the same diagram contains less conclusive evidence for the validity of the questionnaire in identifying the Forming and Norming stages. While removing items did increase the reliability, particularly for Norming, our results do not support the validity of these stages as probed by this questionnaire.

As future work to enhance the validity and reliability of the instrument, there may also be redundancy among certain questionnaire items, which may be remedied by combining them. While modifying the items, cognitive interviews can be conducted with engineering students to make sure the items are interpreted by students as intended [19]. Also, once the questionnaire is modified, additional factor analyses (both exploratory and confirmatory factor analysis) can be conducted to check construct validity of the instrument. Moreover, the modified instrument can be used together with the other existing instrument for the Tuckman team development, in which Miller [10] reported some validity and reliability evidence, to check if the results are consistent with each other.

Conclusions and Recommendations

Our results from the Tuckman Team Development Questionnaire exhibited reliability and validity evidence for its Performing stage, but results for the other three stages do not permit us to support the proposed factors. This causes the questionnaire to be less valid for identifying whether a team is operating in the Forming, Storming or Norming stages. Certain questionnaire items within these stages showed little to no correlation to other items within their stage. However, our results suggest that it is possible to streamline the questionnaire by removing these seemingly conflicting questions to increase the reliability and validity of the instrument in identifying teams within the Storming and Performing stages. On this basis, we recommend that further studies be conducted with a shorter version of the Tuckman Team Development

Questionnaire, by removing the eight items that were shown to be problematic in this study. Additional analysis of student interpretation of the questionnaire items may also reveal what caused the low levels of correlation that we found. This could be carried out, for instance, during cognitive interviews or think-alouds while students respond to the questionnaire. Additional data could be collected with the modified questionnaire and additional instruments that have been developed to measure team performance. Although our study did not suggest strong validity and reliability evidence of the existing Tuckman questionnaire, this study takes an important first step of validating the questionnaire that can be used in the context of first-year engineering teamwork.

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Appendix A: Tuckman Team Development Survey Questions Associated with Each Stage [20]

Note: items in blue were removed from the original survey to improve consistency

No.	***Items for the Forming Stage:***
1	We try to have set procedures or protocols in place to ensure that things are orderly and run smoothly (e.g., minimize interruptions; everyone gets the opportunity to have their say.
5	Team members are afraid or do not like to ask others for help.
10	Team members do not fully trust other members and closely monitor others who work on a task.
15	We are trying to define the goal and what tasks need to be accomplished.
18	We assign specific roles to team members (team leader, facilitator, time keeper, note taker, etc.)
21	There are many abstract discussions of concepts and issues, which makes some team members impatient.
27	It seems as if little is being accomplished with the project's goals.
29	Although we are not fully sure of the project's goals, we are excited and proud to be on the team.
	Items for the Storming Stage:
2	We are quick to get on with the task on hand and do not spend too much time in the planning stage.
7	The team leader tries to keep order and contributes to the task at hand.
9	We have lots of ideas but don't use many as we don't listen but reject before understanding them.
16	Many team members have their own ideas about the process and personal agendas are rampant.
20	The tasks are very different from what we imagined and seem very difficult to accomplish.
23	We argue a lot even though we agree on the real issues.
28	The goals we have established see unrealistic.

31	There is a lot of resisting of the tasks at hand and quality improvement approaches.
	Items for the Norming Stage:
4	We have thorough procedures for agreeing our objectives and planning the way we perform tasks.
6	We take our team's goals and objectives literally, and assume a shared understanding.
11	The leader ensures that we follow procedures, do not argue, do not interrupt, and keep to the point.
13	We have accepted each other as members of the team.
19	We try to achieve harmony by avoiding conflict.
24	The team is often tempted to go above the original scope of the project.
25	We express criticism of others constructively.
30	We often share personal problems with each other.
	Items for the Performing Stage:
3	Our team feels we are all in it together and shares responsibilities for the team's success or failure.
8	We do not have fixed procedures, we make them up as the task or project progresses.
12	We enjoy working together; we have a fun and productive time.
14	The team leader is democratic and cooperative.
17	We fully accept each other's strengths and weaknesses.
22	We are able to work through Team problems.
26	There is close attachment to the team.
32	We get a lot of work done.