Engineering Students’ Self-Reflections, Teamwork Behaviors, and Academic Performance

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Abstract

This complete research paper explores the relationship between engineering students’ self-reflection, teamwork, and academic performance. Prior studies in engineering education emphasize the importance of using effective teaching strategies to enhance students’ academic performances. These strategies help engineering educators in multiple ways, including creating a stimulating learning environment, actively involving students in the learning process, enhancing students’ engagement, and improving students’ learning. Two effective strategies include utilizing collaborative teamwork and providing opportunities for students to reflect on their learning experiences. We simultaneously introduced these two strategies in an engineering class of 120 students to explore the relationship between engineering students’ self-reflection, teamwork, and academic performance. The data were collected using two specific technology tools. We used CourseMIRROR [1]–[3] to collect students’ reflection data, and CATME Smarter Teamwork [4]–[6] to collect students’ peer evaluation of team membership. CourseMIRROR was used in 26 lectures to collect students’ reflection data, and we collected a total of 3430 student reflections (~60% completion). The reflection data comprised of two aspects: 1) muddiest point (MP) which describes the confusing aspect of the lecture, and 2) point of interest (POI) which relates to interesting aspects of the given lecture. Additionally, CATME based data was collected from five dimensions: contributing to the team’s work; interacting with teammates; keeping the team on track; expecting quality, and having relevant knowledge skills and abilities. The CATME team membership survey was conducted four times during the semester. We further collected data on students’ academic performances based on three exams. We also collected students’ race and gender information (i.e., as demographic information). Specifically, we explored the unique contribution of two learning strategies (i.e., teamwork and self-reflection) to predict students’ academic performances after controlling for demographic variables. We used stepwise hierarchical and simultaneous hierarchical regression analyses to explore the unique contribution of each strategy over and above the other. The results indicated that teamwork performance is a strong and positive predictor of engineering students’ performance in their course exams. The study also discusses the implications and future directions of the research.

Introduction

Engineering education research has emphasized improving teaching practices to increase students’ participation, retention, academic performances, and motivating students to pursue careers in STEM areas [7]. To achieve these improvements, prior studies used various methods and changes in engineering teaching practices. Froyd, Wankat, and Smith noted some of these changes in the teaching methods over the 100 years of engineering education. These shifts include an emphasis on engineering science and analytical techniques, focus on outcomes-based education, emphasis on engineering design, applying education, learning, and social-behavioral sciences research, and integration of information, computational, and communications technology in education [8]. To achieve these shifts, studies in engineering education have emphasized using various strategies to improve students’ academic performance. These
strategies include the use of innovative teaching practices such as problem-based learning, project-based approaches, peer and collaborative work, etc. [9], [10]. These strategies support educators in the design of a student-centered learning environment which focuses on incorporating both content knowledge and also helps to enhance professional skills of students, such as critical thinking, effective communication, time management, coping with academic stress, etc.[11], [12]. These strategies served the purpose of keeping students active and engaged in a student-centered learning environment by providing them with authentic activities.

In this study, the engineering students were introduced to two of these strategies by integrating information and communications technology in education. The first introduced strategy was self-reflection. Students were prompted to reflect after each lecture on two aspects: 1) the most confusing aspect of the lecture (Muddiest Point – MP), and 2) the most interesting aspect of the lecture (Point of Interest – POI). The second introduced strategy was the use of teamwork. Students evaluated their peers at four-time points in the semester on various behavioral aspects of teamwork. This study explored the relationship of these two strategies on students’ academic performance while also accounting for their background information, i.e., race and gender. More specifically this study is guided by the following research question:

RQ: What is the unique contribution of two learning strategies (i.e., teamwork and self-reflection) to predict students’ academic performances after controlling for demographic variables?

The paper is characterized in six sections. The next section reviews the existing literature on these strategies and their tools in engineering education followed by sections of research design and methods, results, discussion, and conclusion. The last section also discusses future directions.

Literature Review

Previous literature showed that engineering education needs to prepare students with engineering fundamentals and required knowledge, but should also train them for professional skills [13]. These skills were divided into two groups 1) Personal competence (ability to self-describe, self-reflect, become self-aware or regulate themselves) 2) Social competence (ability to manage relationships and perform with peers, colleagues, and mentors, etc.) [14].

Prior studies on engineering education have used both personal competence (e.g., reflecting on your experiences), and social competence (e.g., being an effective team member) as approaches to enhance students’ learning [13]. Prior studies described being an effective team member as an essential skill for all engineers [15], [16], and it is included as a required core competency in engineering education [17]. Teamwork and evaluating peers helped to recognize others’ perspective, role in the work and behaviors. The interactive teamwork proved to have a strong relationship with students’ learning [18] where teams with more balanced participation among team members performed better [16]. Also, collaboration encouraged empathy and created self-awareness in students [13]. Furthermore, working in teams helped students to build skills of leadership, decision making, trust building, communication, and conflict resolution in an effective manner [19]. Additionally, some studies have shown self-reflection increased students’
self-awareness of their learning, and thus helped to understand the subject deeper [12], [16]. This understanding also helped students to perform better in the courses, and promote skill development [15], [22]–[24].

Although some studies explored the effect of these two learning strategies in engineering classrooms [25], [26], there is no single study that investigated the unique contribution of each strategy on students’ academic performance. For example, Hirsch and Mckenna [25] used reflection as a means to promote teamwork in engineering design education on freshmen and sophomores students. The authors combined teamwork with reflective activities in project-based design work. These activities helped students to learn the desired characteristics of highly effective teams required by the industry. The authors indicated that with these two practices, students not only valued teamwork for engineering design activities but also recognized the importance of self-reflection to understand their own and their peer's strengths. The study also discussed that students could use these strengths to enhance their performance. Although this study used both self-reflection and teamwork, they primarily used self-reflection to improve teamwork and didn’t investigate the unique contribution of each strategy on academic performance.

In addition to using these learning strategies in classroom settings, existing literature provides evidence of the use of innovative technology tools for reflection and for teamwork. For reflection, these tools include the use of e-portfolios such as iPortofolio, PebblePad, ePortofolio [27]–[30], or online learning environments such as blogs [20], [31], [32], or discussion forum [33], [34] to capture what student actually learned by using self-reported evidence. For example, Daniels et al. [20] described a case study which focused on the use of blogs to capture student reflection [32]. In this case study, first year computing students were asked to keep a weekly blog to describe their learning experiences. Students were also responsible for doing peer review by posting comments on their peers’ reflections. The results of this case study indicated that students progressed to different stages of reflection and engaged in dialogic and critical reflection. Also, students not only felt positive about the reflection but also showed satisfaction for the received feedback [20], [32]. In many of these studies, students were reporting their thoughts from a particular direction, e.g., professional skills in general [20], [28], [34], communication or writing skill [29], [31], or critical thinking [31], [33]. In some cases, students were provided with other peers’ reflections, but due to the nature of course requirements, students were asked to read only a few of them. Further, feedback on reflection was a missing aspect. These studies used existing technology tools (which were not originally designed to collect reflections) to capture student reflections.

In a similar way, to promote teamwork and evaluate team members behaviors, various technological tools were used, such as online or web-based tools [35]–[37], CAD-based systems or digital media [38], [39], robotics [40], [41], simulations or virtual labs [42]–[45], and video games [46]–[49]. These tools were reported to enhance students’ collaborations and decision-making processes. While prior teamwork studies have used various technology tools to promote collaboration, none of these studies have discussed the role of peer assessment and self-assessment on the effectiveness of self-directed learning or students’ performances, except for Freeman and McKenzie’s [35] study.
In their study, Freeman and McKenzie discussed the design, implementation, and evaluation of web-based template tool SPARK (Self and Peer Assessment Resource Kit), which creates confidential and accurate assessments of relative contributions of team members. The authors reported that students appreciated the functionality of being able to rate their own and team members’ contributions. In addition, there was evidence of the inflated biased results due to students’ inaccuracy of either being too modest or being able to inflate contributions. The authors also found that students were aware and skeptical about the fairness of the system. In general, although SPARK was a tool for assessment or to manage teamwork, the authors found that the process and tool needed revision for transparency, and to make it generically applicable [35]. The authors suggested that SPARK if integrated into a learning environment, could improve students’ learning of teamwork skills and reduce team problems [35]. Besides its general benefits of being able to rate the students’ contribution, SPARK relied on only three direct aspects of teamwork 1) quality of work, 2) quantity of posting, and 3) effectiveness as a team member on a scale of three where 1 showed no contribution and 2 showed above-average contribution. Also, SPARK functionality had a limitation of being a survey capturing software as a formative assessment. These evaluations were to be exported to a spreadsheet for calculating each individual student’s contribution and to calculate students’ marks (summative assessment). This export to spreadsheet indicated an overhead of exporting survey entries to the summative tool. Also, the assigned marks were very subjective to peers’ evaluations without handling of student inaccuracies or bias.

Overall, the present study addresses the issues by using a specifically designed reflection tool, which prompts students to generate reflections from multiple perspectives and provides a summary of all submitted reflections to both instructors and students. This summary aspect makes it easier for instructors and students to capture the main issues from the students’ point of view. Also, the CATME software for behaviorally anchored teamwork assessment using self and peer evaluation allows students to provide and receive feedback on their contribution to teamwork. CATME further allows the instructor to identify the unfair evaluation by peers based on overly high or low evaluations, relative to other evaluators. Although studies have established the role of these two strategies in students’ academic success, there is limited evidence of combining them in a single class and exploring their unique contributions to predicting students’ academic performances.

Research Methods

Participants

The data were collected from 120 first-year engineering students in a required engineering course at a large midwestern university. The main topics taught in the course include data visualization and analysis, ethics, engineering design, application of computer programming by using Matlab software, and development of mathematical models to solve engineering problems in a collaborative teamwork manner. Students were divided into teams, where each team had 3 to 4 students. We designed a semester-long study, where students submitted their reflection after each lecture individually. Further, students evaluated themselves and their team members at four-time points for the teamwork. In addition, students provided their gender and race information as shown in Table 1.
Table 1 Background Information

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
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<tbody>
<tr>
<td>Gender</td>
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<td>20</td>
<td>120</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White American</td>
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<td>10</td>
<td>74</td>
</tr>
<tr>
<td>International Student</td>
<td>19</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>Non-White American</td>
<td>17</td>
<td>3</td>
<td>20</td>
</tr>
</tbody>
</table>

*Instruments*

The data were collected using two applications: 1) CourseMIRROR (Mobile In-situ Reflections and Review with Optimized Rubrics) [1]–[3] for self-reflection and 2) CATME Smarter Teamwork [4]–[6] for peers’ evaluation in collaborative teamwork.

The CourseMIRROR application was used to collect self-reflection data after each lecture for an entire semester. The CourseMIRROR application prompts students to write a reflection on the concepts and problems discussed in the lecture [1], [50], [51]. Students in this study were asked to write reflections from two perspectives 1) Muddiest Points (MP) and 2) Points of Interest (POI). For MP, the student wrote about the most confusing topic or concept in the lecture. For POI, the student wrote about the most interesting topic or concept of the lecture.

Figure 1: Flow chart to convert reflections into quality scores [24], [26]
In addition to prompting students to reflect on the lecture, the application generated a summary of reflections for each class based on phrase-based natural language processing algorithms. These algorithms are improved over time, so the application effectively generates summary phrases from student responses [52]. In this study, students voluntarily participated in the reflection submission for 26 lectures. There was a total number of 3430 reflections, which indicates a 60% completion rate. The collected reflections for both perspectives was in textual form. These textual reflections were converted into an equivalent quality score based on the rubric in Figure 1. Two human raters independently used the rubric to convert the reflections into the quality score for both MP and POI.

The second application we used was the CATME (Comprehensive Assessment of Team Member Effectiveness) Smarter Teamwork [6], [53], [54]. CATME was used to collect students’ evaluations of their peers in the team project at four-time points during the course, after each milestone of the project. There were three or four students in each team which means for each student, there have been two or three peer evaluations and one self-evaluation. For this report, we are considering students’ peer evaluation only for all five dimensions. Students evaluate their team members on five dimensions: 1) Contribution to teamwork (C); 2) Interaction with teammates (I); 3) Keeping team on track (K); 4) Expecting quality (E); and 5) Having relevant knowledge, skills, and abilities (H). Students rated their peers using 5-level behaviorally anchored rating scales, where 1 indicated poor, and 5 indicated excellent.

In addition to reflection and peer evaluation, students took three exams during the semester. The maximum score for each exam was 120 points. And these exams were graded by teaching assistants and instructors without any involvement from the research team.

Procedure and Analysis

For this study, we have coded the demographic information variable, i.e., race and gender. We have used dummy coding for gender where 0 represents a female, and 1 represents male students. We used a weighted effect coding scheme to describe the race (White, International and Non-White Americans) and used non-white American as the base group. Also, we transformed the data of peer evaluation and students’ reflection quality score. The data is transformed based on the time of course exams occurrence. After conversion, both reflection quality score data and peer evaluation were transformed into three-time points as three sets. The description of changes according to three-time points are as follows:

1) For both MP and POI quality scores, we took an average of the first seven reflections (MP1, and POI1). For each student, we also took an average of all peers’ evaluation in first CATME evaluation for each dimension (C1, I1, K1, E1, H1). We used these sets (reflection quality score set1 and peer evaluation set1) to predict exam1 scores while accounting for demographic information.

2) We took the average of the next eight reflections’ quality score (MP2, and POI2). We also took an average of all peers’ evaluations in second CATME data for each dimension (C2, I2, K2, E2, H2). These sets (reflection quality score set2 and peer evaluation set2) to predict exam2 scores while accounting for demographic information.

3) We took an average of the next ten reflections’ quality score (MP3, and POI3). We also took an average of all peers’ evaluations in third and fourth CATME data for each
To address the research question of determining the unique contribution of two learning strategies (i.e. teamwork and self-reflection) to predict students’ academic performances after controlling for demographic variables, we used two methods as the stepwise hierarchical regression analysis to explore which of these strategies accounts for most variance when predicting academic performance, and the simultaneous hierarchical regression analysis for determining the unique contribution of each strategy.

Results

Two coders individually worked on to generate reflection quality scores. Cohen's Kappa was used to determine the proportion of agreement between the two coders’ judgment on the coding of quality scores. Based on Altman [55] there was a good agreement between the two coders, as $\kappa_{(MP)} = .617$, and $\kappa_{(POI)} = .652$.

Before conducting a regression analysis, we checked for the statistical assumptions. We tested the linearity assumption using scatter plots. Multicollinearity in the data is verified, using the multicollinearity diagnosis variable - Variance Inflation Factor (VIF). We found little or no multicollinearity between predictor variables.

At first, we used stepwise hierarchical regression analysis to determine which strategy reflection quality score (Reflection-QS) and peer evaluation (Peer-eval) accounts for the most variance by accounting for students’ demographic information (Dem-info) and predicting academic performance.

As a method of stepwise hierarchical regression, at step 1, we considered $R^2$ to determine the set which accounts for the most variance. The variable that accounted for most variance became the first set in the hierarchy. In step 2, to identify the second set in the model, we considered the change in $R^2$. The set with higher change is $R^2$ became the second set in the hierarchy. Table 2 shows the values of variances in both steps.

Table 2: Variances to predict exam scores – Determination of variable accounting for the most variance

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Exam 1</th>
<th>Exam 2</th>
<th>Exam 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R^2$</td>
<td>$\Delta R^2$</td>
<td>$R^2$</td>
</tr>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer-eval</td>
<td>.095</td>
<td>.165</td>
<td>.413</td>
</tr>
<tr>
<td>Reflection-QS</td>
<td>.006</td>
<td>.015</td>
<td>.002</td>
</tr>
<tr>
<td>Dem-info</td>
<td>.055</td>
<td>.054</td>
<td>.013</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer-eval with Reflection-QS</td>
<td>.014</td>
<td>.014</td>
<td>.005</td>
</tr>
<tr>
<td>Peer-eval with Dem-info</td>
<td>.062</td>
<td>.042</td>
<td>.023</td>
</tr>
</tbody>
</table>

$\Delta R^2$ represents the changes in $R^2$
In step 1, for all three exams, the Peer-evaluations accounted for the most variance to predict the exam scores. In step 2, to determine the order of stepwise regression, and for increased predictability in the model, we used the value of change in $R^2$. The results of changes in $R^2$ indicate that for all exams, the order of the good model is Peer-eval, Dem-info, and Reflection-QS.

Table 3 Result of change in $R^2$ to explain the variances accounted for by each set

<table>
<thead>
<tr>
<th></th>
<th>Exam 1</th>
<th></th>
<th>Exam 2</th>
<th></th>
<th>Exam 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer-eval</td>
<td>.093</td>
<td>.093</td>
<td>.176</td>
<td>.176</td>
<td>.353</td>
<td>.353</td>
</tr>
<tr>
<td>Peer-eval with Dem-info</td>
<td>.160</td>
<td>.066</td>
<td>.239</td>
<td>.064</td>
<td>.364</td>
<td>.011</td>
</tr>
<tr>
<td>Peer-eval with Dem-info and Reflection-QS</td>
<td>.174</td>
<td>.014</td>
<td>.246</td>
<td>.007</td>
<td>.368</td>
<td>.005</td>
</tr>
</tbody>
</table>

The results of the regression analysis to determine the variance of each set while predicting academic performance are presented in Table 3. These results of the changes in $R^2$ indicate that Peer-eval accounts for 9.3% variance to predict exam 1, 17.6% variance to predict exam 2, and 35.3% variance to predict exam 3. The Dem-info additionally adds 6.6% for exam 1, 6.4% for exam 2, and 1.1% for exam 3. The Reflection-QS data additionally accounts for 1.4% for exam 1, 0.7% for exam 2, and 0.5% for exam 3.

Secondly, to determine the unique contribution of each of these sets to predict exam 1, exam 2, and exam 3, we conducted simultaneous hierarchical regression analysis.

Table 4 Summary of simultaneous regression analysis for the unique contribution of Peer-eval, Reflection-QS, and Dem-info to predict exam scores

<table>
<thead>
<tr>
<th></th>
<th>Exam 1</th>
<th></th>
<th>Exam 2</th>
<th></th>
<th>Exam 3</th>
<th></th>
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<tbody>
<tr>
<td>All sets</td>
<td>.174</td>
<td>.246</td>
<td>.368</td>
<td></td>
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<tr>
<td>Peer-eval and Reflection-QS</td>
<td>.107</td>
<td>.196</td>
<td>.358</td>
<td></td>
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<tr>
<td>Peer-eval and Dem-info</td>
<td>.157</td>
<td>.207</td>
<td>.435</td>
<td></td>
<td></td>
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<tr>
<td>Reflection-QS and Dem-info</td>
<td>.055</td>
<td>.080</td>
<td>.032</td>
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<td></td>
</tr>
</tbody>
</table>

The results of simultaneous regression analysis indicate that Peer-eval has the unique contribution of 11.9%, 16.6%, and 33.6% to predict exam 1, exam 2, and exam 3 respectively. Similarly, Reflection-QS uniquely accounts for 1.7%, 3.9%, and -6.7% to predict exam 1, exam 2, and exam 3 respectively. Dem-info accounts for 6.7% variance to predict exam 1, 5% to predict exam 2, and 1% to predict exam 3 scores. Overall, the results indicate that peer evaluation of teamwork accounts for the most contribution to predict exam scores.

Discussion

Integrating active learning strategies in the large classroom remains a challenge due to the difficulty of keeping students engaged and making them responsible for their learning in an
effective manner. Existing studies in engineering education have discussed various strategies, which may help to make students effective learners. One such approach has been engaging students in self-reflection process which may improve their learning and promote skill development [22]–[24]. In addition to self-reflection, prior studies have also discussed the role of students’ teamwork on their learning and professional development[13], [19]. In this study, we introduced these two strategies in a single engineering class and studied their unique contribution predicting students’ academic performance after accounting for demographic factors (i.e., race and gender). As large classes face the issue of addressing all students needs, in this study, these strategies were introduced using the innovative tools of 1) CourseMIRROR – which collected students’ reflection after each lecture and also automatically summarized the reflection data to provide timely feedback to both instructor and students, 2) CATME Smarter Teamwork which allowed the student to rate each other on a behaviorally anchored scale and gave feedback to students about their own and their team members strengths. In this study, we used the collected data using these tools, and students’ performance on exams (3 exams) to address the research goal of identifying the unique contribution of these strategies on exam performance.

For our research question, we used stepwise hierarchical regression analysis to determine which strategy reflection quality score (Reflection-QS) and peer evaluations (Peer-eval) accounts for the most variance in the data while predicting students’ academic performance and accounting for students’ demographic information(Dem-info). In addition, we used simultaneous hierarchical regression analysis to determine the unique contribution of each strategy and demographic information to predict the three exams. Our results indicate that peer evaluations of teamwork accounts for the most contribution and predicts higher variance for exam scores. These results are novel as no previous study has evaluated the effect of both strategies in a classroom environment with engineering students.

Being one of the preliminary studies, which explored the effect of two strategies on an engineering classroom, this study has some limitations. First, the study had a relatively small sample size (i.e., 120 students). Although these preliminary findings need to be confirmed by applying similar analysis on more extensive data set, the present study was designed where student data (i.e., reflections, peer evaluations, exam scores) were continuously collected for the entire academic semester instead of one-time data collection. Second, in the present study, only peer evaluations had been used, and no data has been collected from students’ teamwork observations or teacher reports about students’ evaluations in the team. We countered this limitation by collecting data at multiple time-points and after each milestone. Third, both instruments relied on students’ provided information on their understanding of concepts, and their peer evaluations. In the case of peer evaluations, the result could be biased because of the students’ preference for their peers, which may have caused an inflation effect or inaccuracies. This limitation was countered as each team member was evaluated by more than one peer (2-3 peers). Fourth in this study two strategies were introduced with the difference in course requirements for these strategies. Self-reflection was voluntary participation; the team member evaluation was a compulsory component of the course and had 15% weight in the course grade. This also may have caused an inflation effect to make peer evaluation as a better predictor of the two strategies. The future implementation of these strategies must account for this course based discrepancy.

Conclusion and Future Directions
In this current study, we discussed the unique contribution of two active learning strategies, i.e., self-reflection and collaborative teamwork on students’ academic performance by accounting for their demographic information (i.e., race and gender). We used two innovative applications to actively introduce these strategies in an engineering classroom of 120 students throughout an academic semester. Beside categorical data of demographic information, we collected the data at various time points with 26 lectures self-reflections, four times peer evaluations after project teams completed a milestone, and studied their effect on three exams. The results of the study showed that collaborative teamwork accounted for the most variance and had a higher unique contribution in predicting all exams, i.e., exam1, exam2, and exam3. The novelty of the research design extends prior research by lending support to mobile learning environments in the context of helping students to engage with the course content more effectively in a large lecture class. Further, this study allows for studying the effect of multiple classroom strategies on engineering students.

Based on this exploration, there are multiple future directions. This study ignores the time aspect of conducting reflections, peer evaluation, and exam scores. Thus one prospective research can be designed around a time series analysis on this data. Also, the study didn’t consider the emotional, or the motivational factors of the students while performing, and this term may have an interaction effect when combined with students’ reflection. A future study based on interaction terms may be designed to see the effect of reflection on students’ performance by emotional, motivational or background variables. Another future direction can be to identify the unique contribution of each CATME dimension to predict students’ performance and likewise unique contribution of the MP and POI to predict students’ performance. Our future studies with the data set will explore the mentioned directions, and we may collect data from engineering students to add power to our analysis.

Acknowledgment

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