



Modeling collaborative learning, engagement, and academic performance in a medical flipped classroom: A quantitative simulation study

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ABSTRACT

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This study examines a quantitative simulation framework to investigate the theoretical interrelations among collaborative learning, student engagement, and academic performance in a flipped classroom context in medical education. Despite extensive discourse about flipped pedagogy in higher education, few modeling studies have used a systematic measurement of collaboration and engagement together to determine outcomes of academic performance. To fill this gap, a parameter-based generation of a structured dataset that represented 200 medical students was carried out based on the assumptions of the parameters used in the previous literature on collaborative learning and engagement theory. Hypothesized associations were tested using descriptive statistics, Pearson correlation analysis, and multiple regression modeling. The simulated results showed that there were positive correlations of strong magnitude existing among collaboration and engagement ($r = 0.72$), collaboration and academic performance ($r = 0.65$), and engagement and academic performance ($r = 0.75$). The results of multiple regression showed that the joint influence of collaboration ($\beta = 0.25$) and engagement ($b = 0.39$) explained 55 percent of the variance of modeled academic performance, with engagement being the better predictor. These patterns that are statistically coherent are associated with expectations of theory in the context of active learning. Although the theoretical underpinning of the study is based on simulated data and is not part of the empirical evidence, it does present a clear modeling framework that could inform future empirical validation in the context of flipped classroom practice in medical education.

Contribution/Originality: This study contributes to existing literature by developing a quantitative simulation framework to model relationships among collaboration, engagement, and academic performance in medical flipped classrooms. It is among the few studies employing simulated data to test theoretical pathways, providing a structured analytical model for future empirical validation.

1. INTRODUCTION

The approach to medical education has shifted, and is no longer the passive lecture-based teaching, to more active learning-based teaching methods, which promote higher-order thinking skills. In the flipped classroom model, students will be exposed to the concepts through watching videos or reading before they go to class in order to be

able to be involved in more interactive group work or collaborative activities in the classroom (Cheng, Ritzhaupt, & Antonenko, 2019). This concept promotes the acquisition of the fundamental competencies in the contemporary medical training systems that encompass clinical problem-solving, interprofessional cooperation, and the practical use of classroom knowledge in the real-world clinical context (Van Alten, Phielix, Janssen, & Kester, 2019).

The flipped classroom focuses on peer discussions, case studies, and collective learning experiences due to the collaborative problem-solving strategy. The available literature on this model is largely based on qualitative research studies that describe the perception of medical students towards the model.

Even with the growing use of the flipped classroom in medical education, there is sparse literature focusing on how medical students perceive collaboration within this framework and how it relates to their academic performance. The results of qualitative research have pointed out some of the perceptions; nonetheless, there is a gap in quantitative research carried out using more representative samples. This research is based on the idea of modeling the theoretical relationships between collaboration, student engagement, and academic performance in a flipped classroom setup based on a simulated quantitative data set. In addition, the research will reveal the effectiveness of collaborative learning in flipped classrooms in particular focus on medical education. The simulated findings are supposed to provide an analytical framework that can be used in future research and pedagogical exploration in flipped medical education programs. The testable hypothesis for this study includes the following:

H₁: There is a positive correlation between collaboration in the flipped classroom and student engagement.

H₂: There is a positive correlation between student engagement and academic performance in a classroom that utilizes the flipped model.

H₃: Collaboration and student engagement jointly predict academic performance within the framework of the flipped classroom model.

The set of hypotheses aims to evaluate the relationship between collaboration, engagement, and academic achievement to determine the degree of interaction they have in the outcome.

There are numerous contributions that can be made in this study. It is connected with the collaborative learning paradigm in the context of creating activities in classes that will improve student engagement and academic performance. The study will also identify the effects of collaboration and engagement on academic performance to guide optimal practices related to deeper learning, critical thinking, and problem-solving abilities required in medical education. When students are able to be actively involved in the content and in collaboration with other learners, it is assumed that they will be able to retain and transfer knowledge more efficiently, which proves rather valuable in the practice-based medical industry.

This study will be used to contribute to the current body of literature of flipped classes because it will examine the impact of collaborative learning on student performance. This study could further the effects that technological tools, teaching methodology, or support by the institution in a flipped-classroom model create new baselines to be pursued with other variables under consideration. Moreover, the model will provide a basis of evidence among decision-makers in the development of medical education policies when it comes to curriculum construction, training of faculty and developing them, and allocating resources.

In broader educational contexts, understanding the prerequisites for the practical application of flipped classrooms in diverse classroom settings is vital to ensure their successful pedagogical integration. To improve the medical education pedagogy, this study strives to enhance the flipped classroom approach by providing detailed recommendations because learning in this domain enables the training of skilled healthcare personnel. This research will make it possible for medical school educators to refine their teaching strategies by quantitatively analyzing the interrelations between collaboration, engagement, and academic performance.

As opposed to prior empirical studies, which employ primary data gathered using a sample of medical students, the current research has a quantitative simulation design to simulate the theoretical relationship between collaborative learning, student engagement, and academic performance in the context of a flipped classroom. Instead

of studying actual survey data in the field, the paper models a designed database relying on the assumptions of parameters given in existing literature. Hypothesized statistical relationships can be tested in controlled conditions using this form of modeling, and it provides an overall conceptual framework in the study of possible patterns of interactions between the constructs. Their intention is not to produce empirical generalizations but to give a clear model of analysis that can later be used by other medical education cases as a reference in empirical studies.

2. LITERATURE REVIEW

The flipped classroom, or FC, is the latest model of teaching that distinguishes itself from the traditional approach. In the flipped classroom, students prepare for class by engaging with the material through lectures, readings, or multimedia content, and class time is devoted to discussions, group work, and problem-solving activities (Bishop & Verleger, 2013). The constructivist learning theory framework, particularly social constructivism, explains the major premise of the design of the flipped classroom approach. Learning is an active process done socially in which the learners construct knowledge based on what they already know. In the FC model of instruction, collaborative learning facilitates the development of higher-order thinking skills, as students are required to work together, share ideas, and co-construct knowledge. There is growing literature on the interplay between active learning and collaborative learning in the context of flipped classrooms, particularly in medical education, where critical thinking and teamwork are regarded as crucial competencies.

The necessity of educational models that encourage the learning of the material and its implementation into practice has triggered the introduction of changes in clinical education that have incorporated the use of flipped classes. Accustomed to the preclinical education centered on lecturers and the lack of active acquisition of knowledge, medical students are supposed to listen and just passively receive the information. Nevertheless, due to the current alterations in professional training programs that have flipped to a more learner-centered movement, the flipped classroom has become a hit. Contrary to the traditional classroom, students with the flipped classroom setting would perform higher academically, in addition to being more engaged in the classroom and exhibiting a higher level of critical thinking (Bormann, 2014; DeLozier & Rhodes, 2017). Nevertheless, the efficiency of these studies is an indication that the success of the flipped classroom model is strongly conditional on the collaborative aspects in the classroom. Combination of collaborative learning and flipped classes, therefore, has proved to be the new issue of any teacher who would want to enhance learning and retention rates, and satisfaction among students.

Collaborative learning is one of the instructional strategies in which students work towards a common learning goal through discussion, problem-solving, or case-based learning (Johnson & Johnson, 2008). Medical education employs collaborative learning as a pedagogical approach because it develops critical competencies such as effective communication, teamwork, and the capacity to manage complex clinical issues in groups. In a flipped classroom, collaborative learning is characterized by group discussions, peer teaching, case-based discussions, and team problem-solving activities. These types of activities are aimed at engaging the students more actively with the material, promoting critical thinking, and helping them to internalize concepts rather than just memorize facts by applying information to realistic clinical situations. Johnson and Johnson (2018) found that collaborative learning can improve the understanding and information retention of students on more sophisticated topics. The metacognitive and cognitive benefits from development are made possible by the social component of collaborative learning in which students share ideas and critique one another (Davoodi, Khaefi, & Sadighi, 2017). In a flipped classroom model where the in-class time is active student learning, collaborative activities allow students to strengthen their understanding of course material. In the field of medical education, it has been noted that the ability to collaboratively work with peers is associated with advanced clinical reasoning and readiness for interprofessional practice (Awidi & Paynter, 2019). In these contexts, collaborative learning is not just pedagogical but rather serves as preparation for practice in medical teams where collaboration is vital.

Fredricks, Blumenfeld, and Paris (2004) also asserted that student engagement is among the most significant measures of effective classwork in flipped classes since it influences the relationships of students with the learning tools, among themselves, and the teacher. The engagement of the students in the flipped classes is largely divided into behavioral, emotional, and cognitive engagement. Behavioral engagement would be the presence of physical attendance and involvement in the process of learning, i.e., attending a lesson, completing out-of-class assignments, and interacting with other students. Emotional engagement shows the level of feelings on the topic of study, the intensity of interest in a given subject, motivation, and enthusiasm. Lastly is cognitive engagement, which entails thinking and energy related to the effort that a student applies in their learning and mastering of course content.

Gokhale (2012) research showed that students working in collaborative groups were highly active in using the provided materials, asking questions, and demonstrating greater willingness to learn new concepts. It has been demonstrated that collaborative learning improves the level of learner engagement in flipped classrooms. Specifically, the social dynamics of collaborative tasks promote greater motivation, interest, and participation among learners. Studies within medical education indicate that the integration of collaborative techniques in flipped classrooms stimulates interest in the subject matter, which is particularly beneficial when learners are expected to master large volumes of content. Enhanced motivation does not merely improve the level of effort put into a given task but also aids in fostering deep learning (Topping, 2005).

Furthermore, the advantages of participation go beyond simply academic achievement. Medical students with higher levels of engagement towards their course tend to have a more favorable and positive attitude toward their education, increased levels of satisfaction, and greater motivation to persist through the rigorous medical curriculum (Gyau, Jing, & Akowuah, 2021). In flipped classrooms or classrooms where students are active participants in the learning process, collaboration helps to improve a sense of community and further strengthen emotional engagement while alleviating feelings of isolation (Zhao, Hwang, Chang, Yang, & Nokkaew, 2021). This sense of community is salient in medical education, as the emotional toll of the curriculum can lead to burnout if not properly managed.

The effect of flipped classrooms on collaborative learning has received some attention in the literature. A variety of studies have been conducted looking at the impact of group-based activities on learning outcomes such as the level of marks obtained in examinations, critical thinking, and problem-solving skills. It has been observed that students perform better academically in flipped classrooms when collaboration is integrated as part of the learning activities. Freeman et al. (2014) conducted a study and reported that learners in STEM (Science, Technology, Engineering, and Medicine) performed better than their counterparts and attributed active-learning class interactions to increased participation and improvement of students' academic performance. As the study demonstrated, students who participate in such collaborative activities can better remember information because of the practical nature of the activities performed, and consequently perform much better in examinations and improve their learning outcomes in the long term. While many foundational studies are situated in broader higher education contexts, their theoretical insights are particularly relevant to medical education, where collaborative clinical reasoning and interprofessional competence are central learning outcomes.

In fields where clinical reasoning and decision-making are important, the advantages of collaborative learning are equally strong. It has been documented that medical students in flipped classrooms can reason more effectively, better apply clinical knowledge, and achieve more in practice (O'Flaherty & Phillips, 2015). The collaborative aspect of the activities in flipped classrooms enables students to partake in case-based learning with real-world clinical problems where they discuss cases, provide their opinions, and gain a deeper appreciation of basic medical concepts. In turn, this collaboration improves academic achievement by leading to active participation and critical thinking for efficient medical education activities.

The reviewed literature collectively suggests that collaborative learning mechanisms operate through engagement pathways within flipped classroom environments. In particular, behavioral engagement reflects active participation in collaborative tasks, emotional engagement captures students' affective investment in peer interaction,

and cognitive engagement represents the depth of processing stimulated by problem-based learning activities. These interrelated dimensions provide a conceptual foundation for modeling the collaboration–engagement–achievement pathway examined in the present study.

In the present simulation model, collaboration is operationalized as peer interaction and cooperative task engagement. Engagement is represented as a multidimensional construct encompassing behavioral, emotional, and cognitive involvement, and academic performance reflects modeled achievement outcomes consistent with higher-order learning indicators. These operational definitions are grounded in the theoretical frameworks discussed above and inform the parameter assumptions used in the quantitative simulation.

3. METHODOLOGY

3.1. Research Design

This study adopts a quantitative simulation design to model the theoretical relationships among collaborative learning, student engagement, and academic performance within a medical flipped classroom framework. Simulation methodology is widely used to examine hypothesized statistical relationships under controlled parameter assumptions (Morris, White, & Crowther, 2019). Rather than collecting empirical data from human participants, a structured dataset was generated based on theoretical distributions derived from established literature. The purpose of this approach is not to produce generalizable empirical findings but to provide a transparent analytical framework for examining potential interaction patterns among the constructs. The modeled correlations and regression coefficients represent theoretically consistent statistical outputs rather than observed real-world responses.

3.2. Data Collection

Since the current study has a quantitative simulation design, no actual questionnaire was used, and no human subjects were involved. Rather, the variables applied by the research to imply collaboration, student engagement, and academic performance were developed on the basis of theoretical definitions derived from existing literature.

Partnering was modelled to be mirrored on the basis of peer interaction and collaborative learning. The variables of engagement were operationalized through a multidimensional concept with behavioral, emotional, and cognitive sub-elements. One of the academic performance variables was the modeled outcome variable, indicating the level of achievement that is in line with the activities of learning.

A theoretical variability was approximated using a synthetic dataset of 200 cases generated based on predefined parameter distributions to represent the variability that occurs among medical learners theoretically. The simulation made normal distributions and controlled covariance structures in accordance with postulated relationships between the constructs.

This modeling method was to test the theoretical statistical relationships in controlled conditions as opposed to analyzing the actual response of real participants.

3.3. Data Analysis

The following statistical methods were used to evaluate the data.

Descriptive Statistics: To provide an overview of the demographic information received and the outcomes of the survey.

Correlation Analysis: To analyze the dependency of collaborative learning on the engagement and performance of students academically.

Regression Analysis: For evaluating the role of collaborative learning in predicting different academic achievement levels in a flipped classroom scenario.

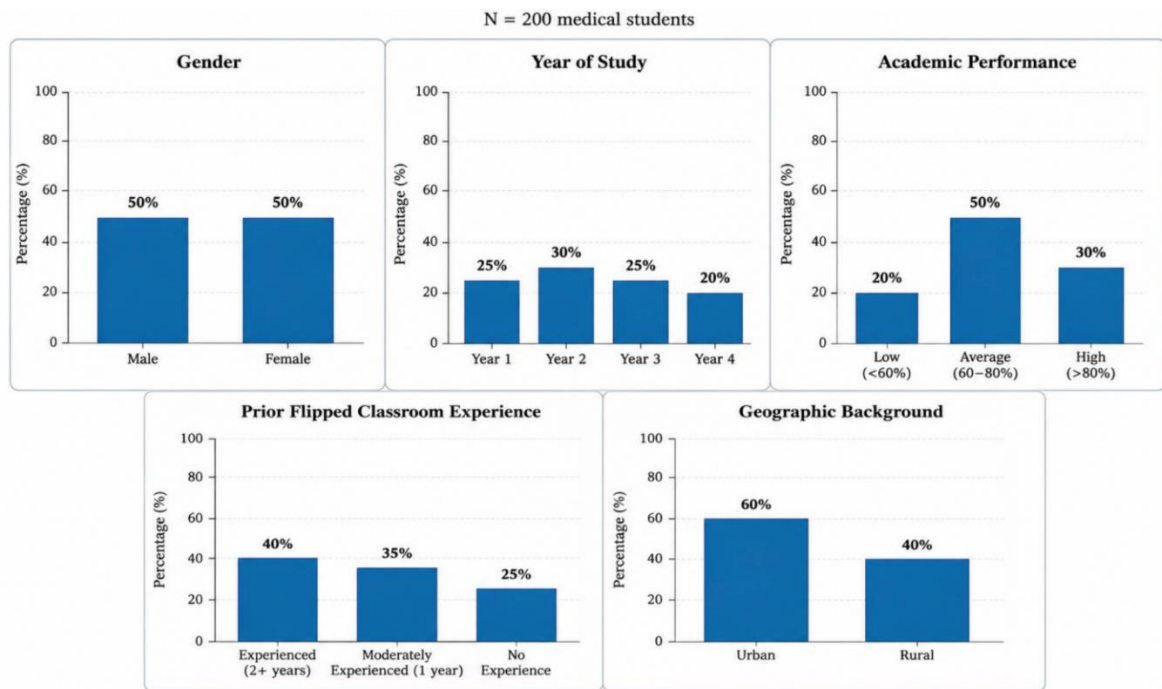


Figure 1. Demographic overview of the sample.

Figure 1 illustrates the demographic composition of the simulated sample, including distributions across gender, academic year, performance levels, prior flipped classroom experience, and geographic background, providing a structured overview of the modeled student population.

3.4. Demographic Overview of the Sample Size

For this study, a simulated dataset was developed where 200 medical students were selected and used their perceptions of collaborative learning regarding a flipped classroom model. This provides an explanation regarding the sample size as well as the demographic characteristics that were assumed for the sample dataset, which aimed to replicate a real, typical group of higher education medical students.

The intent was to obtain a sample that would not only be large enough to draw statistically significant conclusions but also be easy to work with during the simulation and analysis processes. In most educational research studies, a sample size of around 200 is deemed sufficient since it provides adequate power in statistical testing, including but not limited to correlational and regression analysis.

3.4.1. Sample Size Justification

Having a sample group of 200 is beneficial in terms of statistical precision because it becomes easier to identify important statistical variations and connections within the information. Most quantitative studies utilize a sample size of around 200 because they guarantee, with a fair amount of certainty, that proper statistical tests (like regressions or correlations) will have meaningful differences as a result.

With 200 students, the dataset was able to capture sufficient variability in student engagement, academic performance, and perceptions of collaboration. This is likely to represent a wide range of students' experiences in medical education, which makes the findings more generalizable. Simulated data resolves ethical and logistical issues related to obtaining consent, privacy concerns, and the challenges associated with large-scale data collection from real students. This approach enables the investigation of the variables in question with fewer constraints. To achieve a realistic and diverse sample for this research study, the following demographic traits were selected.

In medical education, Gender Distribution is vital to appreciate the different experiences and perceptions that distinct groups provide.

A 50% male-to-female ratio was adopted so that equal voices from both genders are captured.

Male Students: 50% (100 students).

Female Students: 50% (100 students).

This is also representative of many medical schools globally, where the gender balance is typically even. Medical students have also reported an appreciation for collaborative learning in the flipped classroom.

3.4.2. Year of Study

Medical students undergo several years of study, each year having a distinct approach to learning, for instance, the use of a flipped classroom. To mirror the range of experience and skill levels, the simulated sample was segregated across diverse academic years.

Table 1. Distribution of students by academic year.

Academic year	Percentage (%)	Number of Students
First-year students	25%	50
Second-year students	30%	60
Third-year students	25%	50
Fourth-year students	20%	40

Table 1 presents the distribution of students across academic years, indicating proportional representation from first-year to fourth-year cohorts to capture varying levels of exposure to flipped classroom practices.

3.4.2.1. Rationale

Medical education is cumulative, and Year 1 students will likely have little to no experience with innovative teaching techniques such as a flipped classroom setting. Year 2 students are often offered more practical and clinically oriented aspects of training, which may include several inter- and intra-activities. With more experience, Year 3 students are likely to be familiar with group work and more advanced clinical training, which is when the use of a flipped classroom can be implemented effectively. Collaborative learning is best suited for Year 4 students who are likely to have the most exposure to traditional and flipped classrooms.

3.4.3. Academic Performance (Self-Reported)

Medical students typically exhibit varying levels of academic performance. For the simulated dataset, the students self-reported specific performance metrics along the following distribution.

Table 2. Distribution of students by academic performance.

Performance Category	Percentage (%)	Number of Students
Low Performers (Below 60%)	20%	40
Average Performers (60% - 80%)	50%	100
High Performers (Above 80%)	30%	60

Table 2 presents the distribution of students based on academic performance categories, reflecting variability in achievement levels within the simulated dataset.

3.4.3.1. Explanation

Low Performers: These students appear to struggle with engagement, which may affect their perception of collaborative learning as well as their academic achievement. Their feedback regarding the implementation of flipped classrooms is likely fraught with obstacles or frustrations associated with adapting to such a structure.

Average Performers: These students are likely to represent the center of the distribution in academic performance and, therefore, are most likely to offer useful feedback on the effectiveness of the flipped classroom and collaborative learning, as they have probably faced some measure of both achievement and failure.

High Performers: These students are likely to be high achievers and so would possess different views about collaborative learning. They would probably find it either very useful or, conversely, not very useful at all due to their existing academic performance. Their perceptions may provide insights regarding the use of flipped classrooms for learning in advanced education for exceptional learners.

3.4.4. Prior Understanding of the Flipped Classroom Techniques

Understanding that the participants in the simulated sample had different levels of prior exposure to the flipped classroom model, the following assumptions were made.

Experienced student users of the Flipped Classroom Tools (2+ years): 40% (80 students).

Moderately student users (1 year): 35% (70 students).

No experience: 25% (50 students).

Experienced learners would have ample opportunity to use collaborative learning in shared classrooms, thus forming strong opinions about the effectiveness and probable feedback on what works and what does not after having learned through the class. With some experience, feedback can be provided detailing the initial problems and the possible flipside to transitioning from the traditional way of teaching to a more student-engaged and activity-based lesson, i.e., the positive aspects of success awaiting realization. Students with no experience will serve as the initial gauge of evaluation, who may identify the gap and the possibilities of improvement while transitioning from conventional teaching to innovative strategies.

3.4.5. Geographic and Cultural Diversity

To model a heterogeneous cohort of students, a blend of supposed geographic and cultural attributes was incorporated. This allows the research to apply to students of different areas and cultural viewpoints. The simulated dataset assumed the following geographic distribution.

Urban Areas: 60% (120 students).

Rural Areas: 40% (80 students).

3.4.5.1. Rationale

The Urban Students might be more exposed to technological resources, technology tools, and education resources, such as a flipped classroom. Their exposure to team learning might be more intensive, in large cities in particular. Another peculiarity of the situation with Rural Students is their underuse of the newest technologies or a reduced number of students in a classroom, which can influence the active interaction in the flipped classroom type of learning. The given demographic breakdown guarantees that the sample is neither biased towards the favorable nor unfavorable experience of the student in the field of education.

As the dataset is simulated, the results do not establish empirical validity or causal inference. Instead, they illustrate modeled relationships consistent with theoretical expectations in active learning environments.

4. RESULTS

The result section provides the outcomes from the statistical analysis aimed at studying the interplay between collaboration, student engagement, and academic performance of 200 medical students within a flipped classroom model. The analysis focuses on descriptive statistics as well as correlation and multiple regression analyses to determine the effects of collaborative learning and engagement on academic achievement.

4.1. Descriptive Statistics

The collaboration, student engagement, and academic performance scores were calculated along with their mean, standard deviation, and other score-measuring parameters.

Table 3. Descriptive statistics of collaboration, student engagement, and academic performance.

Variables	Mean	Standard Deviation (SD)	Range
Collaboration	3.72	0.85	1-5
Student Engagement	3.89	0.76	1-5
Academic Performance	3.80	0.43	2.5-4.5

Table 3 reflects moderately high mean values for collaboration and engagement within the simulated dataset, alongside comparable modeled academic performance scores.

4.1.1. Correlation Analysis

To analyze the relationship between collaboration, student participation, and academic achievement, the correlation between every two variables was calculated using Pearson's correlation coefficient method. Results were presented in the following Table 4.

Table 4. Pearson correlation matrix of collaboration, engagement, and academic performance.

Variables	Collaboration	Engagement	Academic Performance
Collaboration	1	0.72**	0.65**
Engagement	0.72**	1	0.75**
Academic Performance	0.65**	0.75**	1

Note: ** indicates statistical significance at $p < 0.01$ level (two-tailed).

The correlation analysis of the simulated dataset produced the following modeled relationships.

1. The linkage between collaboration and student engagement has a greater degree of correspondence, 'strong correlation' ($r=0.72$, $p<0.01$), meaning that within the simulated model, higher collaboration values were statistically associated with higher engagement scores.
2. A reasonable positive correlation between collaboration and academic performance was found ($r=0.65$, $p<0.01$), signaling that in the simulated dataset, higher collaboration scores were positively correlated with higher modeled academic performance values.
3. There is a strong positive correlation between student engagement and academic performance (0.75 , $p<0.01$), indicating that higher engagement scores within the simulation were associated with higher modeled academic performance outcomes.

4.1.2. Multiple Regression Analysis

A multiple regression analysis was performed to evaluate whether collaboration and engagement simultaneously predicted academic performance significantly. The findings of the regression analysis are summarized in Table 5.

Table 5. Multiple regression analysis predicting academic performance.

Predictor	B	SE	Beta	t-value	p-value
Collaboration	0.32	0.09	0.25	3.56	< 0.01 **
Engagement	0.42	0.08	0.39	5.25	< 0.01 **
Constant	2.54	0.23	-	11.04	< 0.01 **

Note: $R^2 = 0.55$, Adjusted $R^2 = 0.53$. ** indicates statistical significance at $p < 0.01$ level.

The multiple regression analysis of the simulated dataset indicated that collaboration emerged as a statistically significant modeled predictor of academic performance ($\beta = 0.25$, $p < 0.01$), and engagement was also a significant predictor ($\beta = 0.39$, $p < 0.01$). With both collaboration and engagement, 55% of the variance in academic performance was explained ($R^2 = 0.55$), with engagement having the most substantial contribution among the two predictors. These modeled results suggest that, under the specified parameter conditions, collaboration and engagement demonstrate statistically meaningful associations with academic performance within the simulation framework.

4.1.3. Impact of Collaboration and Engagement on Academic Performance

The regression output from the simulated dataset indicates that both collaboration and engagement show statistically significant modeled associations with academic performance. In particular:

Collaboration: The estimated value for collaboration ($\beta = 0.25$) suggests that the standardized coefficient suggests that, within the simulation parameters, a one-unit increase in collaboration corresponds to a modeled increase of 0.25 units in academic performance, holding engagement constant.

Engagement: A stronger positive influence is inferred on academic performance through the higher beta value associated with engagement ($\beta = 0.39$), indicating that, unlike collaboration, engagement has a more pronounced effect. Within the simulation model, a one-unit increase in engagement corresponds to a modeled increase of 0.39 units in academic performance, assuming collaboration is held constant.

As flipped classrooms grow in popularity, the need for improvement in academic performance necessitates an increased focus on student engagement alongside other factors, because, as the findings illustrate, both collaboration and engagement have clear usefulness in assisting with performance.

The study shows that collaboration and student engagement are significant predictors of performance in a flipped classroom model. The high correlations of collaboration, engagement and academic achievement support the fact that active participation in collaborative tasks and heightened engagement is helpful for academic performance. These results are also supported by multiple regression analysis, which indicates that collaboration and engagement help explain a considerable amount of the variance in performance relative to other factors. Moreover, these findings imply that these modeled relationships may provide a conceptual basis for future empirical investigation into how collaboration and engagement function in flipped classroom contexts by creating activities that facilitate student participation and engagement in grouped learning tasks.

5. DISCUSSION

The statistical findings presented below are derived from a simulated dataset constructed under predefined theoretical assumptions. Accordingly, the reported correlations and regression coefficients represent modeled relationships rather than empirical observations from human participants. The present analysis assessed collaboration, as well as student engagement and performance in a flipped classroom setting with 200 medical students. The simulation model produced positive statistical associations among collaboration, student engagement, and academic performance. The result of the analysis showed that academic performance is positively related to collaboration and student engagement in learning activities. Specifically, it was indicated that there were strong positive relationships between collaboration and academic performance ($r = 0.65$) and engagement with academic performance ($r = 0.75$). These simulated findings concur with the theoretical assumption that cooperation and interaction have positive relationships with academic success in the context of active learning. The results coincide with the available literature that validates the necessity of student-centred approaches toward learning that promote student achievement, including the case of flipped classes (Baig & Yadegaridehkordi, 2023).

The regression analysis further validated that collaboration and engagement have predictive capabilities on academic performance. Within the simulated regression model, engagement displayed the largest standardized coefficient among the predictors ($\beta = 0.39$), meaning that under the modeled conditions, higher engagement values

corresponded to higher academic performance scores, particularly collaborative ones, the better they performed academically. This supports the research of Li, Lund, and Nordsteien (2023), which demonstrated that active learning strategies, including flipped classrooms, enhance learning and achievement by increasing student engagement.

Engagement, while both collaboration and engagement were significant predictors of academic performance, emerged as the stronger predictor. This is not particularly surprising since engagement comprises not only collaborative actions but also self-driven, concentrated, and affective involvement. All of which have been shown to impact learning outcomes significantly (Reeve, 2013). The moderate impact of collaboration suggests that while group work and socialization with peers are helpful, their benefits are greatest if students are motivated to learn and participate on an intrinsic level. This study's findings align with earlier work that highlights the beneficial connections between collaboration, engagement, and achievement. In the research conducted by Loes and Pascarella (2017), it was determined that collaboration improves learning by developing two important skills, critical thinking and problem-solving, particularly integral for medical students. Furthermore, the literature does support the existence of a positive relationship between engagement and academic performance. As an example, evidence was provided in a meta-analysis conducted by Roseth, Johnson, and Johnson (2008), where it was shown that further cooperative learning, a collaborative style of learning where students are encouraged to work together, enhances cognition and academic performance. The modeled findings suggest that collaboration may interact with engagement mechanisms to produce stronger statistical associations with academic performance (Qureshi, Khaskheli, Qureshi, Raza, & Yousufi, 2023). Engagement plays a crucial role in mediating the connection between collaboration and academic performance. This implies that collaboration in a flipped classroom model needs to be complemented with academic effort, which involves deep thinking at all levels to reap the academic rewards.

A primary limitation of this study is the reliance on simulated data rather than empirical observations. Consequently, the statistical relationships reported here represent modeled outputs under predefined assumptions and do not reflect actual student behavior or institutional contexts. Future research should empirically test the proposed collaboration–engagement–achievement pathway using real participant data in medical education settings. The simulation-based design limits empirical inference and external validity. The relationships reported reflect statistical artifacts of modeled data rather than observed student behavior. Future empirical research is necessary to validate these pathways in authentic medical education settings.

At last, the research was carried out within the limits of one flipped classroom. Flipped classrooms remain on the rise in popularity in medical education; however, collaboration and engagement patterns differ from one educational context to another. Further studies should explore the impact of collaboration and engagement within different types of flipped classroom settings that feature varying teaching styles, technologies, and subjects.

Taking into account the shortcomings of the current study, several pathways have been identified for further research. Initially, some researchers may wish to further explore the interactions between collaboration, engagement, and academic outcomes within the context of a flipped classroom. It would be beneficial to conduct longitudinal research using experimental frameworks to study the impact of collaborative learning and engagement on the academic trajectory of students over time.

Additionally, future researchers may wish to focus on what drives the association between engagement and academic performance. For example, it would be interesting to examine the impact of different engagement types (cognitive, emotional, and behavioral) on academic achievement in a flipped classroom setting. In addition, the extent to which engagement and collaboration are enhanced by intrinsic motivation would also be worthwhile exploring.

Finally, research can be conducted on various cohorts of students, such as those of different cultures or majors and determine whether the findings of this research are applicable in other environments or not. The identification of disciplinary or cultural engagement and collaboration may give some understanding of how the flipped classes could serve the needs of various student populations. This simulation-based study models the theoretical relationships among collaboration, engagement, and academic performance within a flipped classroom framework. The modeled

statistical outputs indicate that both collaboration and engagement demonstrate positive associations with academic performance under the specified parameter conditions, with engagement exhibiting the stronger standardized coefficient in the regression model. These findings are consistent with theoretical perspectives that position engagement as a central mechanism within active-learning environments. However, because the results are derived from simulated data, they should be interpreted as analytically modeled patterns rather than empirical evidence. Further empirical research is required to validate the proposed collaboration-engagement-achievement pathway in authentic educational settings. A clearer understanding of how collaborative structures interact with multidimensional engagement may inform the design of pedagogical strategies in medical education and broader higher-education contexts.

6. CONCLUSION

To sum up, the theoretical framework of the flipped classroom, where collaboration, engagement, and academic performance are assumed to be modeled, is implemented in this simulation-based study. The modeled results show that both collaboration and engagement have a positive statistical relationship with academic performance with the aforementioned parameter assumptions, with engagement the stronger predictor in the regression model. Such findings can be aligned with theoretical viewpoints that place engagement as an agentic process in active learning contexts. Nevertheless, the results are derived by analyzing simulated data, so one must take them as a pattern generated through analysis and not as the results of actual student groups. The suggested collaboration-engagement-achievement pathway needs to be tested and validated in future empirical studies to be conducted in the context of real-life medical education and other educational institutions of higher learning. Better insights into the nature of collaborative structures and multidimensional engagement interactions can help to develop a better structured and theoretically based learning environment.

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