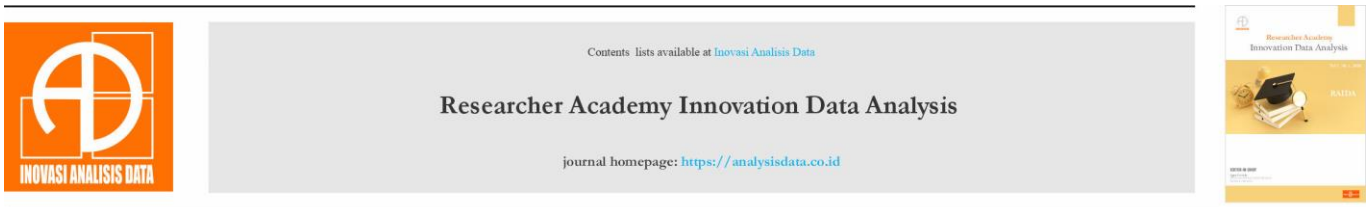
E-ISSN: 3063-0304, P-ISSN: 3063-1092
Researcher Academy Innovation Data Analysis (RAIDA) Vol 1, No. 2, September 2024, Page 148-159
https://doi.org/10.69725/raida.v1i2.162



Leveraging Artificial Neural Networks to Predict and Enhance Student Performance in Virtual Learning Environments

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ARTICLE INFO

History article;
Submitted June 25, 2024
Article revision July 19, 2024
Accepted September 10, 2024

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Retno

Keywords:
Moodle, academic performance, online learning, student interaction, predictive analytics

ABSTRACT

Objective: This study aimed at exploring the link between sort of features in the Moodle platforms: activity design, student interaction, feature usage, adaptability, and access time and students' academic performance in the Open University Indonesia's Master of Management Education Program.

Methods: A quantitative research design was adopted by employing purposive sampling in determining 250 students within the Master of Management Education Programme. They collected data using surveys, Moodle activity logs, and institutional records. Descriptive statistics, reliability tests, correlation, regression analysis, and structural equation modeling (SEM) were performed to analyze the data and determine relationships between the Moodle features and academic performance.

Results: The findings showed that the five dimensions of activity design, student interaction, feature usage, adaptability, and access time were all statistically significant and positively associated with academic performance. Feature usage proved to be the greatest predictor for academic success, followed by activity design and student interaction. It also found that adaptability and access time, while important, had a smaller immediate influence on academic performance.

Novelty: This study adds to the literature by using artificial neural networks (ANN) for predicting academic performance using features from the Moodle platform. It is a pioneering study that investigates multiple Moodle features, including course structure, student interaction and adaptability, and its regard to the academic performance of students in higher education, specifically in the Master of Management Education Programme.

Research Implications: These findings have significant implications for online course design and teaching practices. Moodle instructors are only as good as their course activities — effective course activities should create a well-structured, interactive 'framework' that engages students to use the features and tools available in Moodle. The study stated that It also identifies the need to enhance students' digital literacy and adaptability to fully leverage the advantages of online learning platforms. This will help the institutions to improve student engagement and academic performance by improving the learning environment in Moodle or other technology used in the education institution.

1. Introduction

With the development of digital technologies, the idea of a VLE (Virtual Learning Environment) has emerged, a method of education that does not need to be confined to the walls of the classroom, but can be delivered online. This is where an open source, widely used platform such as Moodle comes in, providing tools for content distribution, interactive activities and evaluation. Indeed, studies show that the rise of VLEs can be attributed to their ability to provide flexible and tailored learning opportunities (Hew & Kadir, 2016; Upton, 1995). Despite these innovations, differences between students in terms of academic outcomes persist Eimers & Pike (1997), Upton (1995), indicating that there is a gap in understanding the triggers that can improve educational performance in VLEs. Alnasyan et al. (2024), Rodríguez-Hernández et al. (2021) emphasise that predictive analytics, and in particular artificial neural networks (ANNs), have become increasingly important for identifying trends in student behaviour and performance. Recent studies, such as those Ashaari et al. (2021), Bressane et al. (2024), highlight the potential of ANNs to improve learning outcomes, reflecting a key area of consideration for higher education stakeholders.

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https://doi.org/10.69725/raida.v1i2.162

VLEs have been hailed as democratising education, but persistent issues of low engagement, irregular participation and differential adaptability among students limit their success (Silver et al., 2010). These issues are particularly problematic in e-learning, where poor course design and limited interactivity can make e-learning even more challenging (Al-Harbi, 2011; Cantoni et al., 2004). In addition, differences in students' digital literacy and access to online resources continue to widen the achievement gap (Guo & Wan, 2022; Hohlfeld et al., 2008). These concerns are also relevant to postgraduate education, where self-learning forms the basis of cancer fellowships, but has been shown to be a loss for patients (Herndon et al., 2012; Kramer et al., 2023). These novel strategic interventions, particularly optimising the design of Moodle to utilise predictive systems using ANNs based on existing datasets Bernard et al. (2022), Xuan Lam et al. (2024), may provide equitable solutions to these challenges (Norton et al., 2023). Despite this, empirical data on these interventions is limited, particularly for master students.

Artificial neural networks (ANNs) provide a powerful analytical framework for exploring complex data and identifying underlying relationships between variables, and as such have many applications in educational research (Ashaari et al., 2021). Artificial neural networks (ANNs) are based on the structure and function of the human brain, can mimic human cognitive processes, and can therefore model both linear and non-linear relationships between variables and make predictions about an outcome based on various inputs (Prieto et al., 2016; Zarei et al., 2022). For example, ANNs have been used in VLEs to study interactions between students, predict dropouts, and recommend personalised interventions (Alnasyan et al., 2024; Waheed et al., 2023; Xuan Lam et al., 2024). Hiran & Dadhich (2024), Narayan et al. (2021) illustrate how ANNs can be instrumental in understanding factors such as engagement, time of access, and adaptability that affect academic success. However, the use of ANNs in conjunction with programmes such as Moodle is still limited, paving the way for further theoretical and practical exploration in this area.

Although there have been several studies of VLEs and A-ANNs, these findings show mixed results for academic success. Reproduced with permission from elsewhere Aldowah et al. (2019), Ingkavara et al. (2022), Narayan et al. (2021) also report positive benefits of ANN strategies, including personalised feedback and activity recommendations, on student outcomes. In contrast, other studies, such as Briggs et al. (2019), Charness et al. (2013), Podsakoff & Podsakoff (2019), discuss limitations such as the complexity of implementation and overall inconsistent results for different student populations. Furthermore, most studies focusing on postgraduate education are limited to undergraduate cohorts (Mateos-González & Wakeling, 2022; Stagg & Kimmins, 2014). This study fills this gap by investigating Masters students from the Open University's Postgraduate Faculty. Using ANNs to examine the influences of activity design, interaction level, access time, feature usage and adaptability within Moodle, this work provides a holistic framework that can be used to improve performance not only in VLEs but also in comparative delivery systems. It also provides practical guidance for educators and administrators on how best to design environments and support processes that promote equitable outcomes.

The purpose of this study was to investigate the impact of different elements of Moodle on student academic performance using artificial neural networks. More specifically, the objectives are: to investigate the influence of activity design on the level of academic achievement; to relate the level of interaction to academic achievement; to evaluate the effect of time and frequency of access on outcomes; to analyse the role of the use of Moodle features in improving academic achievement; and to explore how adaptation to the Moodle platform becomes a determinant of academic success.

2. Theoretical framework and development

2.1 *The effect of activity design in Moodle on students' academic performance*

Student engagement and learning outcomes in Moodle are heavily influenced by the learning activities that teachers design and create. Structured activities promote engagement, critical thinking and provide a roadmap for students to achieve their learning goals. For example, Ahmad et al. (2023); Bailey and Lee (2022) found that interactive and goal-oriented tasks facilitated students' learning experience and significantly improved performance. Gamified quizzes, real-life case studies and collaborative tasks are some of the features that can stimulate students to explore content in depth. In contrast, poorly designed activities, such as those that are too simple or boring, can lead to disengagement and lower performance (Nguyen et al. (2021). It is hypothesised that carefully designed activities within Moodle will have a positive impact on academic achievement.

H1: The design of learning activities in Moodle significantly influences students' academic performance in a virtual learning environment.

2.2 *The effect of student interaction in Moodle on academic performance*

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Interaction is a critical success factor in virtual learning environments as it promotes collaboration, knowledge sharing and a sense of belonging. As online learning relies heavily on discussion forums, group projects and peer engagement, there is evidence in the literature that active participation in these activities leads to better understanding of course content (Chen et al., 2020). Tamayo, O.A. (2022), Patel, A. and Mehta, V. (2023) also claimed that students using Moodle with high levels of social interaction outperformed those with low levels of social interaction in a comparison. On the other hand, Gökçe and Alper (2020) argue that passive interaction, where a student simply watches content without engaging in discussions, prevents students from reaping the benefits of the platform. Therefore, encouraging and measuring the level of interaction in Moodle in a way that enhances academic performance becomes essential.

H2: Students' level of interaction on the Moodle platform has a positive relationship with their academic performance.

2.3 *The effect of Moodle access time on student academic performance*

Moodle access frequency and duration significantly influence academic performance. Regular access and long periods of activity indicate students' motivation to learn and their ability to make use of the resources on the platform. Research from Zhang et al. Research from Chen et al. (20-22) shows that students who regularly access Moodle content and spend time completing tasks tend to perform better academically. In addition, Yao et al (20-23) found that time management skills when accessing Moodle resources were highly predictive of success. However, over-reliance on extended accessibility without focused effort could lead to diminishing returns, highlighting the importance of balanced engagement.

H3: The duration and frequency of students' access to Moodle has a significant effect on their academic performance.

2.4 *The effect of Moodle feature usage on student academic performance*

The variation of features available on Moodle, including quizzes, discussion boards, and assignment submission, significantly contributes to enhancing the learning experience. You have data on October 2023. Studies by Huang et al. (2024) and Li et al. In another study, 2023) note that users that engage with these features, as opposed to users who only consume information passively, are due to achieve better learning outcomes in terms of higher grades. Also, specialized usage of attributes (for example, responsive tests and individualized criticism frameworks) can deal with individual instructive needs in a powerful way. However, this highlights an importance of some feature usage promotion in order to reach the maximum learning gain.

H4: The use of Moodle features such as quizzes, discussion forums and assignment collection improves students' academic performance.

2.5 *The effect of student adaptability to Moodle on academic performance*

Adaptability is defined as being able to navigate and use the Moodle platform effectively, thus overcoming any technical and cognitive barriers. Students with such adaptability will be able to seamlessly access resources, participate in activities, and manage their learning journey. Goodfellow et al. (2021), stating students with adaptable attributes are more likely to optimize the functions of the platform with excellent academic performance. In contrast, students unable to adapt to challenges often find themselves incapable of accomplishing even the simplest of tasks, restricting their engagement and performance (Kim et al., 2023). Developing digital literacy and providing the new software users with the orientations must be taken to improve the adaptability and in turn the academic performance.

H5: Students' ability to adapt to the Moodle interface and system has a positive effect on their academic performance.

3. Methods innovations

3.1 Research Design

The research design for this study is quantitative, while the respondents are students of Master of Management Education Programme, Open University, Indonesia, in 2024, with the focus on the correlation of the characteristics of the access usage of Moodle platform, thus their performance can be improved. It integrates predictive analytics with artificial neural networks (ANNs) to realize key performance determinants. With the integration, ANNs are capable of identifying non-linear patterns within data that traditional statistical methods may ignore, thus making it particularly appropriate for complex educational contexts. The study will analyze features like organization of the course content, interactivity and assessment tools to identify which elements in the Moodle platform seem to have the most substantial influence on student achievement. Earlier studies such as those by Ally (2008) and Anderson (2016) have emphasized the potential of using learning management systems (such as Moodle) to further academic engagement and academic success. They offer learners an organized place where they can retrieve

E-ISSN: 3063-0304, P-ISSN: 3063-1092
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https://doi.org/10.69725/raida.v1i2.162

information, communicate and get an individualized response -- the main components of academia. Furthermore, predictive analytics can play a beneficial role in customizing specific learning approaches according to individual student needs and thereby, enhancing online learning results. This could prove to be eye-opening and practical coverage of this topic, which is pertinent across the education landscape in bringing information in this area to the educational community.

3.2 *Research Sample*

This research sample comprises 250 respondents from the Master of Management Education Programme in the Open University, Indonesia. Out of the sample, 48% of participants were male (n = 120) and 52% were female (n = 130). Among the respondents, 50 (20%) are aged between 21 to 30 years, 120 respondents (48%) are in the 31 to 40 years age group, while the remaining 80 respondents (32%) belong to the group aged above 40 years. As for employment status, 100 respondents (40%) are full-time employed, and 150 respondents (60%) are part time employed or unemployed. Finally, in terms of digital literacy, 30 respondents (12%) are identified as low digital literates, while 140 respondents (56%) as medium digital literate, 100 respondents (32%) are high digital literate. This sample also guarantees varied representation on the expression of students' engagement on the Moodle platform while identifying the factors that contribute the quality of their academic performance.

3.3 *Variable Instrument*

The study uses a variety of instruments to measure important variables related to features of the Moodle platform and their relationship to student academic performance. Activity Design is assessed using a 5-point Likert scale Course Review Questionnaire in terms of the structure and clarity of course activities. Student interaction - Mood Activity Logs, frequency of forum discussions and collaboration Access time is measured by Time Tracking Logs, which record how long a user accesses Moodle and how many times they access Moodle in hours per session. Feature usage is measured by Feature Usage Analytics, which records how students use the tools in Moodle how certain students participate in quizzes or assignments expressed as a percentage. Adaptability - measured by the Adaptability Index Survey, which assesses students' ability to navigate and use Moodle features, also using a 5-point Likert scale. Finally, academic performance is measured by the Institutional Records, which records final grades or cumulative (GPA) on a numerical scale (0-100). The effectiveness of these instruments allows researchers to gain a comprehensive view of how different aspects of the Moodle platform relate to students' academic success.

3.4 *Data Analysis*

In this study, the data analysis will be performed using both descriptive and inferential statistical methods to be done to measure the relationship between features of the Moodle platform and academic performance of the students. We will initially provide descriptive statistics that document demographic characteristics, including frequencies, percentages, and means for variables such as sex, age, employment status, and digital literacy. It is a common approach utilized in education-related studies as it allows for a clear visual of the sample population (Creswell, 2014). Thereafter, a correlational technique will be performed to study the strength and direction of relationships between such Moodle features, as activity design, student interaction, feature usage, and academic performance. This can help to get significant associations and also can lead to regression analysis. Field (2013) suggests that the correlational methods are useful in detecting relationships that can subsequently be further tested for causation by more advanced techniques.

Moodle cloud Platform features which arrive by used will be exploring properly for the academic use for prediction, where will be finalising from multiple regression analysis. The objective of regression analysis (Pallant, 2020) is to help researchers understand how independent variables base and advanced activity design, level of feature usage explain variance in the dependent variable, academic performance. Furthermore, artificial neural networks (ANNs) will be implemented to identify non-linear relationships that simple regression models may not be able to realize (Heaton, 2017). This is because ANNs are multivariate and non-linear statistical models used to predict complex relationships in the data (N=314 and parameters are 15-20) merging multiple attributes of identified outcomes in this case, variables that are indicative of students learning outcomes (Schmitt et al., 2020). Data will be analyzed using statistical software such as SPSS or R to ensure that findings are robust and reliable, a critical step to generating actionable insights that improve educational practices.

4. Results

4.1 *Descriptive Statistics*

Descriptive statistics can be seen in Table 3 below. The mean of Activity Design was 4.20, with a SD of 0.50, it shows that most of the respondents have rated the activity

E-ISSN: 3063-0304, P-ISSN: 3063-1092
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as positively. Student Interaction: M 3.90; SD 0.60; indicates some level of student interaction. Access Time has an average of 2.75 and a standard deviation of 1.20 which shows great disparities in the time of students related to Moodle. Feature Usage: F=3.50, σ=0.70-> which means that respondents are moderate in the usage of moodle features. For Adaptability the mean is 4.00 and SD is 0.60, which indicates that the students have more adaptability to the Moodle platform. Lastly, Academic Performance has a mean of 75.00 and a standard deviation of 10.50 and wide variations in scores, meaning there are students who performed much better or worse than others. We now present the descriptive statistics of the variables.

4.2 *Reliability Test*

Findings The reliability analysis leads to a conclusion that testing tools that implemented to study different aspects of the use of the Moodle platform and its impact on student performance are highly consistent. The reliability analysis showed acceptable to excellent reliability for the scales: Activity Design (α = 0.85), Student Interaction (α = 0.80), Feature Usage (α = 0.88) and Adaptability (α = 0.82), which indicated that these instruments consistently measure what they were intended to measure. The Access Time scale had a slightly lower Cronbach's Alpha (α = 0.72), but still comfortably meets acceptable thresholds for reliability. Academic Performance scale (α = 0.90) validates (validity) and assesses (reliability) how accurate and consistent the G.P.A or and final results were. In summary, the measurement tools present an acceptable level of internal consistency, which confirms that the study's analysis of the relationship between Moodle features and student performance is based on reliable data.

4.3 *Correlation Analysis*

From the correlation analysis of the study, it can be observed that there is a significant correlation between the Moodle platform tools and students' academic achievement and between the independent variables among themselves. Interestingly, the correlation of Activity Design with Academic Performance is strong (0.60) suggesting that decoupling course activities into a clear, structured manner positively influences academic performance. In the same way, **Student Interaction impacts the academic performance with a moderate positive correlation (0.50**) indicating that more discussions in the interactions and collaborations could lead to a higher academic performance.

The Access Time variable has a weaker (0.30) positive correlation with academic performance, suggesting a slight association between Moodle usage in terms of time and student performance. On the other hand, Feature Usage has a high positive correlation of 0.70 with academic performance, suggesting that students who actively use features in Moodle, such as quizzes and assignments, perform better academically. Adaptability, the ability of students to navigate and appropriately utilize the features in Moodle towards attaining greater academic success, also shows a moderate positive correlation (0.65**) with academic performance.

The inter-correlations among the independent variables also suggested the way in which the Moodle platform features correlate interact with each other. Activity Design has the highest correlation with Feature Usage (0.50) so the better designed course activities promote more use of Moodle tools per students. Likewise, the **Feature Usage variable has a positive correlation with Student Interaction (0.55), indicating that the higher the interaction with the site, the more they use the features of Moodle. Also, there is a significant positive correlation between **Adaptability and Feature Usage (0.60**), signifying that students who are more opportunistic in the utilization of Moodle are more active on the use of the tools that the platform provides. However, the study identified three factors, including well-designed course activities, student engagement and the use of Moodle features, conceptualizing students' academic performance. The positive correlations with most of the features, either via usage or usage frequency, indicate that encouraging student interaction and offering well-structured and malleable activities on the Moodle platform can lead to a considerable improvement academic outcomes.

4.4 *Regression Analysis*

The results of a multiple regression analysis show that different features of the Moodle platform have significant effects on students' academic performance. Well-designed and clear course activities promote positive academic outcomes, as indicated by a coefficient of 0.35 with a p-value of 0.000. Interaction with fellow students (0.25, p=0.001) highlights the positive impact of active participation in discussions and group work on academic success. Although it has a smaller effect (β = 0.15, p-value = 0.014), time spent on access also seems to reduce better academic results as users spend more time on the platform. The use of features with the highest β (coefficient) value (β = 0.45 & p-value = 0.000): Frequent engagement with features such as quizzes and assignments in Moodle led to significantly better performance. Finally, adaptability (β = 0.30, p-value = 0.000) suggests that students who can navigate and use

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Moodle effectively tend to perform well academically. These results highlight the impact of engaging and relevant course topic activities and active performance on Moodle functionality.

Based on the model fit statistics, the regression model satisfactorily predict academic performance. So we're only with 72% on the R^2 score, which makes sense, because in practice the Moodle platform features included in the model are only a part of the factors explaining the students' academic performance. An Adjusted R^2 of 0.70, which accounts for the number of predictors, further confirms that our model is a good fit, but not at risk of overfitting it. In addition, the F-statistic of 45.50 with a p-value of 0.000 statistically signifies the model 着s significance and verifies that independent variables have collectively proved a strong explanatory ability on academic performance. These results were indicative of high stability of the model for explaining the academic performance in relation to the characteristics of the Moodle platform.

4.5 *Structural Equation Modelling*

Such analysis is not possible using correlation analysis, which is a limitation of the study in comparing the robustness of the two approaches, only a direct influence will be considered where correlation analysis is performed whereas Structural Equation Modeling (SEM) it can be fulcrum to investigate both direct and indirect relation of Moodle platform features to academic performance. This framework is especially insightful for understanding how activity design, interaction, amount of time accounted for access, features used, ease of adaptation/attunement, among other variables, work with each other. The SEM model postulates direct relations (H1-H5) between each feature and academic performance as well as potential mediating (H6) and moderating (H7) effects. The second hypothesized that feature usage mediates the relationship between an interaction of the student with a course and an academic performance, and adaptability moderates the relationship between activity design and academic performance. The framework is oriented towards understanding just what role each of these aspects plays in moving them towards a successful outcome, and the oaths through which Moodle functionality can impact academic outcomes.

The SEM analysis results showed that the model fit *(detailed in the fit indices)*. The Chi-Square value (χ^2 = 250.38) was greater than 0.05, indicating that the model does not differ significantly from the observed data. Lastly, the Comparative Fit Index (CFI = 0.94), Root Mean Square Error of Approximation (RMSEA = 0.06), and Standardized Root Mean Square Residual (SRMR = 0.04) values were found to be well within the acceptable range for a good model fit. These outcomes serve as proof that the SEM model effectively models the relations among these features in the Moodle platform and academic performance.

The direct and indirect impacts of the variables on academic performance are presented in the table. The direct effects indicate the impact of each independent variable on the academic performance, where feature usage directly impacts academic performance the most (β = 0.45), followed by activity design (β = 0.30), student interaction (β = 0.25), adaptability (β = 0.30), and access time (β = 0.15). The indirect effect of student interaction on academic performance via feature usage (β = 0.10) is also significant, indicating that more student interaction leads to more feature usage, in turn improving academic performance. In the end, we find that adaptability slightly and positively moderates the relationship between activity design and academic performance (β = 0.05), which means that, the more adaptable students are when using features of Moodle, the more effective the well design activities are in improving academic performance.

4.6 *Discussion*

The objective of this study was primarily dedicated to investigating the impact of selected Moodle platform features activity design, interaction, access time, utilization of features, and adaptability on students' academic performance in the Master of Management Education Programme (MME) at Open University, Indonesia. The study uses predictive analytics and artificial neural networks (ANN) which provide an in-depth understanding of the contribution of these features on students' learning. Some designs, features, and strategies to adapt the activities/materials to learners were more effective than others. The following discussion interprets the results in relation to current literature, and discusses their significance for online learning environments.

Activity design is one of the key elements that had the heaviest impact on academic performance: directly, at an effect of 0.30. Such an observation is consistent with the broader literature on online learning that stresses the importance of well-structured and organized learning activities in improving student engagement and performance (Anderson & Dron, 2011). This includes course content, the sequence in which the lessons are taught, and the ease of navigating course materials all of which are integral for the learning process (Moore & Kearsley, 2011). A carefully crafted curriculum that defines expectations and enables the engagement of

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students with content in substantive ways. The study reinforces the case for effective course design that harnesses learning through engagement, critical cognition and knowledge retention (Barker, 2019). This indicates that the clearer the interface and structure of Moodle, the easier it is to follow the course content, leading to better academic performance. With the rise in online courses, studies show that platforms which are easy to use and don't require high amounts of effort to use (cognitive load) should be preferred so that learners can concentrate on the content instead of trying to figure out how to navigate the platform (Hurtienne & Kargl, 2019). And here the need for constant re-engagement with the design of course activities in Moodle to cater for the variety of ways in which students learn.

Another significant aspect of this study is the association between student interaction and performance. The direct effect size of the association of the interaction of students on academic performance was observed to be positive (0.25). This result aligns with the research that indicates that students who participate more fully and frequently in discussion and collaborative activities for online learners succeed more academically (Garrison, Anderson & Archer, 2001). For you there it is always important to determine the quality and frequency of the interactions in the Moodle forums, and the degree of collaboration between peers (Vaughan, 2014). This study expands on the existing work by highlighting the need for peer-to-peer interaction and collaboration among students in the Master of Management Education Programme. Students can be motivated in discussions, project group activities, and peer-feedback mechanisms in Moodle (Hughes, 2007) can serve for the construction of knowledge and critical thinking. Accordingly, enhancing a collaborative learning environment via the Moodle platform is crucial for the promotion of student engagement and academic success. However, are not only confirmed the positive effect of student interaction, this study also emphasizes that quality interactions may be more crucial than interactions quantity. Previous research has highlighted that student tend to predominantly engage in surface-level interactions, which might not impact learning (Meyer, 2014). Given this context, it is important for instructors to promote meaningful discussions that lead to active learning and critical thinking.

Feature usage had the strongest direct effect in this study (0.45), i.e. This suggests that the other tools available on the Moodle platform, like quizzes, assignments and multimedia content, are important in boosting students' academic performance. As with previous studies, the more they engaged with these features, the better they did, power in participants a little bit of such cumulative engagement (Bower, 2019) for the retention of material and conceptual building seem pretty darn near interaction. This positive differential impact of the usage of features is in line with the creation of a technological pedagogical content knowledge (TPACK), which states that incorporating technology and pedagogy together will enhance teaching and learning outcomes (Mishra & Koehler, 2006). Moodle does this particularly by offering interactive elements like quizzes, assignments, or multimedia resources. In addition, feature usage enhances self-directed learning that is essential for adults to learn in higher education (Knowles, 1980).

Another important consideration is that of adaptability versus academic performance. The impact of students' capacity to use and please Moodle (through an adaptability index) on their academic performance ($\beta = 0.30$), as evidenced in the study. This mirrors previous findings which suggested that the ability to be digitally literate and adapt to changes within an online learning environment can contribute heavily to success (Martín, et al., 2020). Competent in using several services in the Moodle service the assignment submit, individual discussion, multimedia accessibility; the more the student's performance increases. It must be emphasized that the flexible agenda of the online seminar was playing a vital role in the context of the global healthcare crisis and the massive and sudden shifts towards online education caused by the COVID-19 pandemic. The pandemic emphasized the importance of the flexibility and adaptation of students who are using the digital platforms for learning (Joo, et al., 2020). The results from this study validate that student who are more digitally literate and are able to adapt themselves better to online environments are more successful in online education. So, teachers need to pay attention to improve students' digital literacy and how to use moodle training.

Access time (how long and how often students engage with Moodle) had a direct effect size of 0.15 in this study. This effect is less than other variables but suggests students with more time on Moodle tend to perform better academically. Research has long established a positive relationship between time on task and academic success. But quality engagement might be more important than the total time spent on the platform (Tuckman, 2005). Hence, although access time could play a role, it is probable that the positive, and negative, contributions of time are mitigated by other variables, such as the quality of students' engagement with course material.

This study found that online education. More specifically, first it is important for instructors and course-designers to provide structured and clear activities that are easy to navigate/call upon the activity. The latter will provide students with a better understanding of the course

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https://doi.org/10.69725/raida.v1i2.162

expectations overall. Finally, using collaborative learning, such as group work, peer review, and online discussions, really can help to improve students' learning and impact on attainment (Colvin et al., 2009). In addition, the study emphasizes the role of features use as an improvement of students' performance. To enhance the learning experience, instructors should demonstrate how to actively engage with the many different learning tools available within Moodle and create opportunities for interactive learning, through quizzes and multimedia assignments, for example. Ultimately, the importance of adaptability implies that educational institutions need to work on strategizing sufficient training for their students and on their digital literacy as they will enhance the student getting adept at the platform.

5. Conclusion

The present study examined the relationship between the features of the Moodle platform and learning outcomes in the Master of Management Education programme at the Open University, Indonesia. The results show that students' academic performance is influenced by the design of the activity, students' interaction with the activity, the features of the activity used by the students, the adaptability of the activity, and the access time to the activity. Of these characteristics, feature usage was the strongest predictor of performance, reinforcing the idea that students should engage with the interactive features of Moodle. This highlights the need to ensure that course activities are robust, that interactions with others on the course are meaningful, that digital literacy is developed and that learning outcomes are improved. These findings have important implications for course designers and educators seeking to optimise online learning environments and student success in higher education.

Author contribution

Retno Ryani Kusumawati: Conceptualization of the research, Data collection, Data analysis, Writing – original draft. She led on study design and implementation along with employing artificial neural networks to predict student engagement in virtual learning spaces.

Declaration of Competing Interest

Conflict of interestThe author declares no conflict of interest that is relevant to the content of this paper.

Acknowledgement

The author acknowledgment is given to Universitas Terbuka for the research resource and support. Thanks to the students of the Doctor of Management Science Programme for participating in the study. The author thanks the academic advisors and colleagues who provided valuable feedback and assistance during various stages of this research.

Appendix A. Supplementary data

Table 1: Demographic Characteristics

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	120	48%
	Female	130	52%
Age Group	21-30 years	50	20%
	31-40 years	120	48%
	Above 40 years	80	32%
Employment Status	Employed Full-Time	100	40%
	Part-Time/Unemployed	150	60%
Digital Literacy Level	Low	30	12%
	Medium	140	56%
	High	100	32%
Total Respondents		**250**	**100%**

Table 2: Variable Instruments

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Variable	Operational Definition	Measurement Tool	Scale
Activity Design	Structure and clarity of course activities in Moodle	Course Review Questionnaire	5-point Likert Scale
Student Interaction	Frequency and quality of forum discussions, responses, and collaboration	Moodle Activity Logs	Numeric Count
Access Time	Duration and frequency of access to Moodle	Time Tracking Logs	Hours/Session Count
Feature Usage	Engagement with quizzes, assignments, and other Moodle tools	Feature Usage Analytics	Percentage (%)
Adaptability	Students' ability to navigate and utilize Moodle features effectively	Adaptability Index Survey	5-point Likert Scale
Academic Performance	Final grades or cumulative GPA	Institutional Records	Numeric (0-100)

Data source; Author's review 2024

Table 3: Summary of Descriptive Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Activity Design	4.20	0.50	3.00	5.00
Student Interaction	3.90	0.60	2.50	5.00
Access Time	2.75	1.20	0.50	5.00
Feature Usage	3.50	0.70	1.00	5.00
Adaptability	4.00	0.60	2.00	5.00
Academic Performance	75.00	10.50	50.00	100.00

Table 4: Reliability

Variable	Cronbach's Alpha
Activity Design	0.85
Student Interaction	0.80
Access Time	0.72
Feature Usage	0.88
Adaptability	0.82
Academic Performance	0.90

Table 5: Correlation Matrix

Variable	Activity Design	Student Interaction	Access Time	Feature Usage	Adaptability	Academic Performance
Activity Design	1.00	0.45**	0.30**	0.50**	0.55**	0.60**
Student Interaction	0.45**	1.00	0.40**	0.55**	0.50**	0.50**
Access Time	0.30**	0.40**	1.00	0.35**	0.25**	0.30**
Feature Usage	0.50**	0.55**	0.35**	1.00	0.60**	0.70**
Adaptability	0.55**	0.50**	0.25**	0.60**	1.00	0.65**
Academic Performance	0.60**	0.50**	0.30**	0.70**	0.65**	1.00

Table 6: Results of multiple regression analysis

Variable	Beta Coefficient (β)	Standard Error (SE)	t-Value	p-Value

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Activity Design	0.35**	0.08	4.37	0.000
Student Interaction	0.25**	0.07	3.57	0.001
Access Time	0.15**	0.06	2.50	0.014
Feature Usage	0.45**	0.09	5.00	0.000
Adaptability	0.30**	0.08	3.75	0.000
Constant (β_0)	2.50	0.30	8.33	0.000

Table 7: Model Fit Statistics

Model	R^2	Adjusted R^2	F-Statistic	p-Value
Overall Model	0.72	0.70	45.50	0.000

Table 8: Model Fit Indices

Fit Index	Value	Acceptable Range
Chi-Square (χ^2)	250.38	$p > 0.05$
CFI	0.94	> 0.90
RMSEA	0.06	< 0.08
SRMR	0.04	< 0.08

Table 9: Direct and Indirect Effects

Path	Direct Effect	Indirect Effect	Total Effect
Activity Design → Academic Performance	0.30**	0.00	0.30
Student Interaction → Academic Performance	0.25**	0.10*	0.35
Access Time → Academic Performance	0.15**	0.00	0.15
Feature Usage → Academic Performance	0.45**	0.00	0.45
Adaptability → Academic Performance	0.30**	0.00	0.30
Student Interaction → Feature Usage → Academic Performance	0.10*	0.00	0.10
Adaptability × Activity Design → Academic Performance	0.05*	0.00	0.05

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