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PAPER

Attitudes of Economics Students Towards Teamwork at University

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ABSTRACT

Teamwork has an undeniable benefit in finding creative and effective solutions to situations in both work and school environments. Teamwork training can be seen as a necessary condition for the career growth of every individual. This article aims to explore students' attitudes towards teamwork, identify the reasons for positive and negative attitudes of students towards teamwork, and measure their level of satisfaction with various aspects of teamwork. The survey utilized a non-standardized questionnaire comprising closed-ended items, multiple-choice items, and scaled items. Out of the 148 respondents, the majority expressed a positive attitude towards teamwork across different aspects, with varying reasons and levels of satisfaction. Statistical analysis of the data revealed that there is no statistically significant difference between the groups with positive and negative attitudes towards teamwork regarding their views on the reasons that cause positive or negative attitudes. However, there is a significant difference between the groups in their evaluation of all the aspects of teamwork, except for difficulty and unfairness. Students with positive attitudes towards teamwork place significantly more importance on relationships within the team, express higher satisfaction with recognition for good achievements and with the opportunity to help others, and they also prioritize the opportunity to assist others more than students with negative attitudes.

KEYWORDS

university students, reasons of positive and negative attitudes to teamwork, personality aspects of teamwork, level of satisfaction and importance of aspects

1 INTRODUCTION

Many employers express the opinion that university graduates are generally quite well prepared in terms of theoretical knowledge, but often lack presentation, stress management and teamwork skills [1]. Nowadays, also in companies, the individual form of further education is dominant while it is important to use the potential of team training and to pay more attention to the formation of learning teams,

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as well as to a systematic approach to team education and training [2]. Failure to adopt a teamwork strategy is often considered as an important cause of failure in implementing change in organizations [3].

The role of the university is not only to theoretically prepare students for a certain field but also to develop students' personal and social skills that they will use in practice. It is important to develop physical and practical abilities, socioemotional and technical capabilities of students in accordance with the OECD intentions [4]. The development of socioemotional and interpersonal capabilities is undoubtedly aided by the implementation of teamwork in the training of students. A team can be characterized as a group of people working together who have common time-limited goals and are interdependent in achieving these goals [1]. The benefits of team functioning include pooling of knowledge of members who can do the job better and come up with more creative solutions, increased flexibility, elimination of individual mistakes. Team learns to compromise, increases self-esteem of individuals, reduces fears and stress, motivates, etc. [1] [5] [6]. Possible negatives of working in a team are poor communication and the possibility of conflict, suppression of individuality, having to adapt to a common goal, time-consuming, competitive individuals striving for self-assertion and, on the other hand, the inability to assert a good opinion by less combative team members, group laziness in a situation when they consider the assigned task as easy or unimportant, think that their own contribution is unimportant or others slack off the work [7] [8].

The expertise of the members is important for the success of the team, but also the structure of their personalities and the way they get along. In a successful team, everyone finds their role and accepts it [9]. According to Hackman [10], a team is effective when it 1) achieves the goals for which it was designed; 2) meets the needs of its members; and 3) is viable or sustainable over time. Team functioning is not effective when a task that does not require teamwork needs to be solved and when there is a great deal of uncertainty in the team [11]. The most successful teams are those that achieve a high level of maturity. Mature teams are those in which members interact regularly, coordinate resources, orient their behavior toward collective success, and in which members identify with the team [12]. A crucial condition for successful teamwork is the willingness and decision to work together in a team, which means seeing oneself as part of a larger whole—the team. It is important to teach students that we can only work together if we admit that we are not perfect, can listen to others and do not defend only our own opinions [13]. Team teaching gives students the opportunity to develop independent critical thinking, and learn to choose from offered alternative views, solutions. Plurality of opinions helps students understand that there is no absolute certainty and ultimate truth [14]. C. De Pablos Heredero et al. [3] relate the quality of teamwork to the quality of communication, specifically its characteristics such as accuracy, frequency of communication with each other, timeliness (timeless) and type of problem-solving communication.

Falls et al. [15] defined cooperative higher education which creates the basis of teamwork. They proposed five pillars necessary to build effective collaboration: 1. positive interdependence, 2. face-to-face promotive interaction, 3 individual accountability and personal responsibility, 4 frequent use of interpersonal and small group social skills, 5. frequent, regular group processing of current functioning. Fathi et al. [16], who addressed the effectiveness of teamwork training in a university setting, considered the following as determinants: financial resources, instructor qualifications, institutional support, time span of teamwork training, complexity of instruction, teamwork assessment, curriculum design, course redesign, planning and implementation, and student workload.

Research findings related to directly implemented teamwork in the school and its aspects showed that students who worked in a team, as opposed to working individually, were significantly more likely to agree that the course achieved the stated learning objectives. This opinion was influenced by the factors of 1) student satisfaction with the teamwork experience; 2) instructor leadership related to teamwork; 3) the presence of slackers in the teams; and 4) team size. It was instructor guidance on how to work effectively in teams that significantly changed students' satisfaction [17]. The findings of Gero [18], who examined the attitudes of heterogeneous teams of students from different backgrounds in interdisciplinary lessons, also show that from the student' perspective, the positives of teamwork significantly outweighed the difficulties associated with teamwork, with the greatest benefit being that the interdisciplinary team contributed to filling knowledge gaps. Salim et al [19] reported that students valued the learning experience of working in a team because of the opportunity to discuss the materials and exercises and to realize the extent to which they understood the topics. On the contrary, unequal contributions and unfair grading, individual differences among students, inappropriate team formation, assignment, and instructional design led to negative teamwork experiences [20].

Teamwork is often associated with game-based learning, but also with project-based learning [21] [22]. Vodernichova [23], who applied play in higher education, concluded that simulation play in teams deepens knowledge and skills, increases creativity and confidence, as well as motivation and interest. Modern project-based learning, corresponding to the requirements of our times, must develop social, communication and other skills for the needs of the 21st century, and therefore requires students to work together on a project (team solution), not just solve projects individually [24]. The opportunity to work as a team with classmates is one of the fundamental principles of project-based learning [25] and one of the significant benefits that students perceive associated with project-based learning [26].

2 METHODOLOGY

Two years ago, a new course was designed and introduced at our faculty, which combines project solving and teamwork. The aim of our research was to find out how teamwork is perceived by the students who took it during the academic years 2021/2022 and 2022/2023, and to deduce measures to improve the teaching of this subject on this basis.

The following research questions were established:

1. What is the attitude of students towards teamwork in general?
2. What are the reasons for students' positive attitudes towards teamwork or its benefits?
3. What are the reasons for negative attitudes towards teamwork and/or perceived problems?
4. How do students evaluate teamwork in terms of selected aspects directly related to teamwork?
5. To what extent are they satisfied with teamwork in terms of aspects related to their personality and what importance do they attach to these aspects?

In relation to the objectives above, we tested the following hypotheses:

H1: We hypothesize that there are differences in the reasons for positive attitudes towards teamwork between the group with positive attitudes and the group with negative attitudes towards teamwork.
H2: We hypothesize that there are differences in the reasons for negative attitudes towards teamwork between the group with positive attitude and the group with negative attitude towards teamwork.
H3: We hypothesize that there are differences in the evaluation of the observed aspects of teamwork between the group with positive attitude and the group with negative attitude towards teamwork.
H4: We hypothesize that there is a difference in the level of satisfaction with the observed personal aspects of teamwork between the group with positive attitude and the group with negative attitude towards teamwork.
H5: We hypothesize that there is a difference in the level of importance of the observed personality aspects of teamwork between the group with a positive attitude and the group with a negative attitude towards teamwork.

2.1 Participants

148 respondents – students of the 2nd year of the bachelor's degree at the University of Economics in Bratislava, who took the course Project Management and Teamwork in the years 2021–2023, participated in the research. It was one of the optional courses, which students enrolled in at their own discretion. The sample consisted of 75 females and 73 males studying the finance programme with a mean age of 20.8 (SD = 0.80). Students were placed in positions in the teams according to their performance on the Belbin's Team Roles Test.

2.2 Instrumentation

The survey was conducted using a non-standardized questionnaire that we constructed for the purpose of this research based on the stated objectives. The questionnaire included closed-ended, multiple choice and scaled items.

The primary question, which was determinant for the division of respondents into groups with positive and negative attitudes towards teamwork, answered by the respondents and was a closed question: I like teamwork with yes/no response options. This was followed by 2 multiple-choice items aimed at finding out the reasons why they have a positive and negative attitude towards teamwork. Response options were compiled based on the literature reviewed and preliminary discussions with students. Respondents chose among them and they are presented in Tables 1 and 2. In the next items, respondents expressed on a scale of 1 to 6 (1 – completely disagree to 6 – completely agree) the extent to which they found teamwork interesting, difficult, motivating, popular, enjoyable, knowledge-enhancing, needed, beneficial, developing personal qualities such as responsibility, independence, etc., limiting, and unfair. We have deliberately chosen this scale so that the students' opinions would lean towards the positive or negative pole.

In the last part of the questionnaire, the respondents were asked to evaluate the following aspects based on their own experience of teamwork: their relationships in the team, their prestige in the team, the opportunity for personal growth, the opportunity to make independent decisions, the opportunity to help others, appreciation for good results, the opportunity to think and act independently, their authority in the team. Again, the ratings were expressed on a scale of 1 to 6 (1 – completely disagree, 6 – completely agree). They evaluated each aspect from two perspectives: a) in terms of how satisfied they were with it and b) in terms of how important it was to them. We pursued these two perspectives on the grounds that attitude includes both emotional and cognitive aspects. Satisfaction primarily reflects the importance of the emotional and the cognitive side of attitude.

One-factor and multi-factor analysis of variance (ANOVA) was used for statistical analysis. The statistical significance of the differences between the views on teamwork among the group of respondents with positive and negative attitudes towards teamwork were examined.

3 RESULTS

Out of the 148 undergraduate students, 90.55% (134) said they had a generally positive attitude towards teamwork. Only 9.45% (14) of undergraduate students expressed a negative attitude.

The reasons for the positive attitude towards teamwork are shown in Table 1. The whole group of respondents particularly appreciates the fact that each team member contributed something different, the opportunity to work with classmates on common outcomes, finding more diverse solutions to problems, and the fun of the teaching process. The three reasons mentioned above were also in the top three ranks in the group with positive attitudes towards teamwork. The group of students with a negative attitude equally appreciated that everyone in the team contributed something different, that they learned to find and defend their point of view, and that they found several diverse solutions to the tasks.

Table 1. The reasons of positive attitude of students towards teamwork (%)

The Reasons of Positive Attitude of Students Towards Teamwork	Relation of All Participants (n = 148)	Relation of Participants Who Like Teamwork (n = 134)	Relation of Participants Who Do Not Like Teamwork (n = 14)	Difference (D)
I could easily get a good grade with the help of other classmates	19.60	19.40	21.43	–2.03
I could collaborate on common outcomes with my classmates	62.16	68.66	.00	68.66
I could apply my creativity	46.62	49.25	21.43	27.83
We found several different solutions to the tasks in the group	54.73	55.97	42.86	13.11
Each of us contributed something different	77.70	78.36	71.43	6.93
My passivity in the group disappeared	5.41	4.48	14.29	–9.81
I learned more by working with my classmates on the common outcomes	37.16	40.30	7.14	33.16
The teaching process was more fun	54.73	58.21	21.43	36.78
I learned to find and defend my own opinion	39.87	38.81	50.00	–11.19
Other	.68	.00	7.14	–7.14

Table 2 shows the reasons that cause students' negative attitude towards teamwork. In the whole sample of respondents and in the group with positive attitude towards teamwork, the reasons related to time aspect are in the first two places. Students do not like that the tasks took a lot of time and they could not organize their time as they would like. More than a quarter are bothered by working with someone irresponsible. In the group with a negative attitude, the reasons mentioned above related to time and the fact that they have to work with someone at all because they prefer to work alone were equally frequent. The last item also shows the largest percentage difference (almost 40%) between the groups, which is logical. More than 18% said that working with someone less capable was also a problem for them. More than 16% are bothered by having to adapt regarding solutions and ideas. The smallest difference between the groups was in the item "I was not satisfied with the final solution, but I had to accept it".

Table 2. The reasons of positive attitude of students towards teamwork (v %)

The Reasons of Positive Attitude of Students Towards Teamwork	Relation of All Participants (n = 148)	Relation of Participants Who Like Teamwork (n = 134)	Relation of Participants Who Do Not Like Teamwork (n = 14)	Difference (D)
I was working with someone irresponsible	25.68	25.37	28.57	–3.20
I worked with someone less capable	12.16	10.45	28.57	–18.12
I've worked with someone who doesn't "fit" me	10.81	11.19	7.14	4.05
Working on tasks took more time	43.92	44.03	42.86	1.17
I've had to work with someone at all because I prefer to work alone	7.43	2.99	42.86	–39.87
I couldn't organise my time and work as I would have liked, (I had to constantly adapt about time),	27.03	25.37	42.86	–17.48
I had to constantly adapt to solutions, ideas	6.76	5.22	21.43	–16.21
I was not satisfied with the final solution, but I had to accept it	14.86	14.93	14.29	0.64
Other	16.89	17.91	7.14	10.77

Statistical analysis showed that there was no statistically significant difference between the groups with positive and negative attitudes towards teamwork in their views on the reasons that cause positive attitudes (P-value = 0.16973435). The same can be stated regarding the reasons for negative attitude towards teamwork, where there is also no statistically significant difference between the groups (P-value = 0.19818121).

In Table 3, we report how undergraduate students evaluate teamwork in terms of selected aspects directly related to teamwork. Students perceive teamwork as interesting, beneficial, enjoyable, developing qualities such as responsibility and independence, extending knowledge, needed, motivating, and slightly less popular. Lower values were obtained in the last two cases, which was due to the fact that negative adjectives were used. However, if we reverse the result, we can conclude that they do not perceive teamwork as limiting and unfair.

Based on the statistical analysis, we can conclude that there is a statistically significant difference between the groups with positive and negative attitudes towards teamwork in the evaluation of all but two of the observed aspects. We did not find a statistically significant difference in the opinion that teamwork is challenging (P-value = 0.93752959) and unfair (P-value = 0.70749109).

Table 3. Evaluation of teamwork in terms of selected aspects (%)

Evaluation of Teamwork	Relation of All Participants (n = 148)		Relation of Participants Who Like Teamwork (n = 134)		Relation of Participants Who Do Not Like Teamwork (n = 14)		Difference (D)	Average Value***
	N*	Y**	N*	Y**	N*	Y**		
Interesting	13.51	86.49	8.21	91.79	64.29	35.71	–56.08	4.74
Challenging	48.65	51.35	49.25	50.75	42.86	57.14	6.39	3.67
Motivating	24.32	75.68	21.64	78.36	50.00	50.00	–28.36	4.30
Popular	37.16	62.84	32.09	67.91	85.71	14.29	–53.62	3.97
Enjoyable	20.95	79.05	17.91	82.09	50.00	50.00	–32.09	4.48
Extending knowledge	22.97	77.03	20.15	79.85	50.00	50.00	–29.85	4.46
Needed	22.30	77.70	19.40	80.60	50.00	50.00	–30.60	4.41
Beneficial	14.86	85.14	11.94	88.06	42.86	57.14	–30.92	4.66
Developing qualities such as responsibility, independence	20.27	79.73	17.16	82.84	50.00	50.00	–32.84	4.53
Limiting	68.92	31.08	70.90	29.10	50.00	50.00	20.90	2.89
Unfair	82.43	17.57	82.09	17.91	85.71	14.29	–3.62	2.31

Notes: *Participants who evaluate negatively (scale 1 – 3). **Participants who evaluate positively (scale 4 – 6). ***Scale from 1 to 6 (6 – maximum).

The extent to which students are satisfied with the selected aspects related to their personality and the extent to which these aspects are important to them is shown in Table 4. Across the whole sample of respondents, the highest satisfaction was with group relationships and appreciation for good results achieved. In third place was the opportunity to help others. Prestige in the team was also ranked above 80% of all students, but only 60% of them considered it important, and authority in the team was also ranked lower, with only 66% considering it important. Satisfaction was lowest with the opportunity to make decisions independently.

A statistically significant difference emerged in four cases. Students with positive attitudes toward teamwork found relationships within the team significantly more important (P-value = 0.00017829), were significantly more satisfied with the opportunity to help others (P-value = 0.00261011), and also placed significantly more importance on the opportunity to help others than students with negative attitudes (P-value = 0.00023638). These students are also significantly more satisfied with appreciation for good results achieved (P-value = 0.04834551).

Table 4. Evaluation of satisfaction and importance of selected personality aspects (%)

Evaluation of Satisfaction and Importance of Selected Personality Aspects		Relation of All Participants (n = 148)		Average Value***	Relation of Participants Who Like Teamwork (n = 134)		Relation of Participants Who Do Not Like Teamwork (n = 14)		D
		N*	Y**		N*	Y**	N*	Y**	
Relationships in team	satisfaction	10.14	89.86	5.22	8.96	91.04	21.43	78.57	–12.47
	importance	12.16	87.84	4.93	9.70	90.30	35.71	64.29	–26.01
Prestige in team	satisfaction	18.92	81.08	4.74	19.40	80.60	14.29	85.71	5.11
	importance	39.86	60.14	3.86	39.55	60.45	42.86	57.14	–3.31
Possibility of personal growth	satisfaction	22.30	77.70	4.47	21.64	78.36	28.57	71.43	–6.93
	importance	23.65	76.35	4.53	22.39	77.61	35.71	64.29	–13.32
Possibility of independent decision-making	satisfaction	26.35	73.65	4.32	25.37	74.63	35.71	64.29	–10.34
	importance	27.70	72.30	4.30	29.10	70.90	14.29	85.71	14.81
The opportunity to help others	satisfaction	12.84	87.16	4.87	10.45	89.55	35.71	64.29	–25.26
	importance	22.30	77.70	4.50	19.40	80.60	50.00	50.00	–30.60
Appreciation for good results achieved	satisfaction	10.14	89.86	5.05	8.96	91.04	21.43	78.57	–12.47
	importance	18.24	81.76	4.70	17.16	82.84	28.57	71.43	–11.41
The possibility of independent thinking and action	satisfaction	25.00	75.00	4.40	23.88	76.12	35.71	64.29	–11.83
	importance	21.62	78.38	4.39	23.13	76.87	7.14	92.86	15.99
Authority in team	satisfaction	18.24	81.76	4.68	19.40	80.60	7.14	92.86	12.26
	importance	33.78	66.22	4.18	32.84	67.16	42.86	57.14	–10.02

Notes: *Participants who evaluate negatively (scale 1 – 3). **Participants who evaluate positively (scale 4 – 6). ***Scale from 1 to 6 (6 – maximum).

4 DISCUSSION AND CONCLUSION

The majority of students in our research sample declared a positive attitude towards teamwork as it was implemented in the Project Management and Teamwork course. This we consider to be a very good result and a solid basis for the use of teamwork in university courses. Although there is a low percentage of students with negative attitude towards teamwork in our research sample, we should try to manage teamwork to change their attitude in a positive direction.

The reasons for the positive attitude towards teamwork were the fact that each team member contributed something different, the opportunity to collaborate with classmates on common outcomes, finding more and different solutions to tasks, and the fun of the learning process. The three reasons mentioned above were in the top three ranks for the whole group and for the group with positive attitudes towards teamwork. The group of students with a negative attitude equally appreciated that everyone in the team contributed something different, that they learned to find and defend their opinions, and that they found multiple and varied solutions to the tasks. A comparison of the groups shows a difference in the item "I could collaborate on common outcomes with my classmates", which was not marked by anyone in the group with a negative attitude. This finding confirms the truthfulness of the answer to the primary question exploring the attitude towards teamwork. Students with negtive attitudes also much less value the fun of the class and do not perceive that they learn more when working together on common outcomes than those with positive attitudes. There is also a nearly 28% difference between the groups in the opportunity to apply their creativity, with several authors suggesting that greater flexibility and more creative solutions overall is one of the characteristics of a well-functioning team [1] [6]. Students with a negative attitude towards teamwork rate higher that they learned to find and defend their opinion, that their passivity in the group disappeared and they could easily get a good grade with the help of their classmates. These three reasons imply a focus of students with negative attitudes towards teamwork more on themselves and their advantages, which is directly opposed to the intrinsic setup or attitude to teamwork. The crucial condition for successful teamwork is primarily the willingness and decision to work together in a team, which means to perceive oneself as part of a larger whole—of the team [13]. This group of students identified the fact that their passivity disappeared and they got a better grade thanks to their classmates as a positive reason influencing their attitude towards teamwork. Hence, the challenge for teachers implementing the course is to make sure that the passivity of no one in the group disappeared and that no one gets a good grade for the work and performance of others. This is a well-known problem that is also addressed in the context of student assessment in project-based learning. One of the ways to address the problem of passivity and disinterest of some students in the classroom is precisely the application of teaching forms and methods that are aimed at motivating and activating students, which certainly includes teamwork [13]. From the perspective of students with a positive attitude towards teamwork, this may be a factor that makes them dislike teamwork. Therefore, it should be consistently insisted that everyone must be involved in teamwork. We hypothesize that the group with a negative attitude is more likely to be introverts, who generally prefer to work alone and cannot be assertive to the same degree as those with a positive attitude. It is therefore necessary to provide them with more space to express their thoughts and ideas. We therefore see the fact that they have learned to find and express their opinions as a plus point of teamwork for this group. However, there is still a challenge for the team leader to create more space for them to apply their creativity, which they are much more dissatisfied with than the group with a positive attitude towards teamwork. However, despite some differences between the groups compared, there was no statistically significant difference of opinion on the reasons that cause positive attitudes towards teamwork, so we conclude that **H1 was not confirmed.**

Regarding the negatives of teamwork, students identified those known from the literature, such as the time-consuming nature of teamwork and the need to adapt [7], [8], but in our sample, working with someone irresponsible or less capable also occurred. In this context, it is important for team leaders to appeal to students not to underestimate any of their classmates and not to point out their negative characteristics. To make them aware that everyone has certain skills and qualities that can contribute to the effectiveness of the team, the team leader should highlight something about each student in the team that is related to his/her role to show his/her contribution. Positive is that students from both groups have no problem accepting the final solution and understand the essence of the democratic approach. Although we observed some differences regarding the reasons for negative attitudes towards teamwork, there was no statistically significant difference between the groups and **H2 was not confirmed.**

In H3, we hypothesized that there are differences in the ratings of the observed aspects of teamwork between the group with positive attitudes and the group with negative attitudes towards teamwork. We found that in the whole sample of respondents, teamwork was positively evaluated in terms of interestingness, usefulness (as beneficial), fairness, necessity, its impact on the development of personal qualities such as independence and responsibility, and the area of knowledge. Just below the threshold of 4, which already corresponds to a positive attitude, were also popularity and difficulty (challenging). There was a statistically significant difference between the groups with positive and negative attitudes towards teamwork in the evaluation of all but two of the aspects studied, namely, difficulty (as challenging) and unfairness, and we therefore conclude that **H3 was partially confirmed.** Although there is often controversy about the fairness of the evaluation of students in teamwork and project solving, we conclude from the results that the evaluation as it was set up was correct. It included the assessment of individual outputs as well as collaborative team outputs and involved the teacher, team leaders and other team members commenting on the assessment. The difficulty of the course and the project was also set appropriately, as it was considered challenging/unchallenging by about half of the students.

Searching the level of satisfaction and the importance of those aspects of teamwork that are related to the personal characteristics of students working in teams showed that students with positive attitudes towards teamwork are significantly more satisfied with the opportunity to help others and with the relationships within the group. These aspects are also significantly more important to them than to students with negative attitudes. They are also significantly more satisfied and appreciation for good results achieved is more important to them. Based on these findings, we conclude that **H4 and H5 were only partially confirmed** because out of the 8 aspects studied, there was a difference in satisfaction in only three and importance in only one aspect. It shows that students with a positive attitude towards teamwork are generally more oriented towards relationships and feedback from other people. Although not significantly, the results suggest that students with negative attitudes towards teamwork are more satisfied with their authority and prestige in the team, but they are less important to them than to students who like teamwork. Almost 12% fewer students with negative attitudes are satisfied with possibility think and act independently, but it is more important to them. This again confirms that these students prefer their individuality to working in a team.

In terms of satisfaction and importance evaluation, future work needs to focus particularly on those aspects of teamwork where there was the greatest difference in satisfaction and importance evaluation, namely where there is low satisfaction with the aspect they consider important. These are the possibility to think and act independently and the possibility to make independent decisions in a group with a negative attitude. Since we are concerned with building team spirit, the solution lies in explaining and pointing out the benefits of a certain subordination to others. We find it useful to point out what they themselves have mentioned as a benefit of teamwork, and that is the fact that they have learned to find and defend their opinion through teamwork.

Based on the results so far, we can conclude that the development of students' teamwork at our university within the subject Project Management and Teamwork is going in the right direction. The development of teamwork in PBL creates learning processes where students are immersed in a collaborative experience that develops personal skills, enhances leadership, negotiation, creativity and brings students closer to the real world of project management [27].

The success of an educational process focused on teamwork requires that both teachers and students take an active role and responsibility. In the case of the teacher for leadership, in the case of the student for their own learning. On the part of the students, it is active participation, sharing information, knowledge, experience, ideas, completing assignments and meeting deadlines, maintaining cooperative relationships, willingness to help, making decisions together, fostering team spirit and cohesiveness. Leadership involves providing direction and motivation to others to meet project objectives; creativity and the ability to think and act in original and imaginative ways, using individual and collective ideas to find common benefits in the project; negotiation as a means by which people can resolve their disagreements and maintain good relationships within the project team [27]. The recommendations and the activities mentioned in relation to the role of the team leader and the teacher, will be tried to be implemented to take the development of students‘ teamwork to an even higher qualitative level. It is the instructor‘s guidance on how to work effectively in teams that can make a significant difference in student satisfaction [17].

Due to the limited research sample, we cannot generalize the results. In the future, it will be necessary to expand the research sample and compare the results obtained on the sample of economics students with the results obtained by students from other disciplines. Our research method for detecting attitudes was a questionnaire; however, another method for detecting attitudes, e.g. the semantic differential method, could also be considered. Supplementing these with whole-team discussion or observation could also be useful. In next academic years, we plan to explore students‘ attitudes towards teamwork in more detail with respect to the different team roles according to Belbin, the use of which we have found to be successful.

5 REFERENCES

[1] P. Horváthová, *Týmy a týmová spolupráce*. Praha: ASPI – Wolters Kluwer, 2008.

[2] S. Barnová, M. Duda, M. Matulčíková, G. Gabrhelová, and T. Hrivíková, "Further Professional On-the-Job Training of Employees in the Digital Era." *International Journal of Engineering Pedagogy (iJEP)*, vol. 12, no. 5, pp. 54–67, 2022. https://doi.org/10.3991/ijep.v12i5.32523

[3] C. De Pablos Heredero, S. Haider, and A. García Martinez, "Relational Coordination as an Indicator of Teamwork Quality: Potential Application to the Success of e-Learning at Universities." *International Journal of Emerging Technologies in Learning (iJET)*, vol. 10, no. 2, pp. 4–8, 2015. https://doi.org/10.3991/ijet.v10i2.4102

[4] A. Drigas, G. Papanastasiou, and C. Skianis, "The School of the Future: The Role of Digital Technologies, Metacognition and Emotional Intelligence." *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 9, pp. 65–85, 2023. https://doi.org/10.3991/ijet.v18i09.38133

[5] F. Farkas, "The Role of Leadership in Knowledge Management and Knowledge Transfer." In *Knowledge Transfer, Small and Medium Sized Enterprises and Regional Development in Hungary*. Szeged: JATEPress, 2003.

[6] A. Bencsik, E. Noszkay, and I. Marosi, "Teamwork in Education." *Problems of Education in the 21st Century*, vol. 10, pp. 10–20, 2009.

[7] L. Kolajová, *Týmová spolupráce: Jak efektivně vést tým pro dosažení nejlepších výsledků.* Praha: Grada Publishing, 2006.

[8] F. Bělohlávek, *Jak vést svůj tým.* Praha: Grada Publishing, 2008.

[9] R. Meier, *Úspěšná práce s týmem*. Praha: Grada Publishing, 2009.

[10] J. R. Hackman, "The Design of Work Teams." In *Handbook of Organizational Behavior,* J. W. Lorsch, Hoboken, NJ: Prentice-Hall, 1987, pp. 315–342.

[11] J. Navarro, J. L. Bosch, M. Palacín, M. Solé, R. Berger, D. Leiva, F. Ceppi, and J. Castellano, "Teamwork: Assessment of Teamwork Competence in Higher Education." In *Proceedings of the 3rd International Conference on Higher Education Advances, València, Spain*, June 2017, pp. 21–23. https://doi.org/10.4995/HEAD17.2017.5507

[12] R. Meneses, R. Ortega, J. Navarro, and S. D. de Quijano, "Criteria for Assessing the Level of Group Development (LGD) of Work Groups: Groupness, Entitativity, and Groupality as Theoretical Perspectives." *Small Group Research*, vol. 39, no. 4, pp. 492–514, 2008. https://doi.org/10.1177/1046496408319787

[13] Ľ. Velichová and D. Orbánová, "Students' Teamwork as a Way to Overcome Their Passivity." In *Sapere Aude 2019: Společnosť a profese učitele, Reviewed Proceedings of the 9th International Scientific Conference.* Czech Republic: Hradec Králové, vol. 9, pp. 193–199, 27–29 May 2019.

[14] Ľ. Velichová and D. Orbánová, "Possibilities of Team Teaching in Economic Education." In *Sapere Aude 2013: Pozitivní vzdělávání a psychologie, Reviewed Proceedings of the 3rd International Scientific Conference.* Czech Republic: Hradec Králové*,* vol. 3, pp. 446–450, 25–29 March 2013.

[15] I. Falls, V. Bahhouth, C. M. Chuang, and J. Bahhouth, "Factors Influencing Students' Perceptions of Online Teamwork." *Sage Open*, vol. 4, no. 1, 2014. https://doi.org/10.1177/2158244014525415

[16] M. Fathi, M. Ghobakhloo, and A. Syberfeldt, "An Interpretive Structural Modeling of Teamwork Training in Higher Education." *Education Sciences*, vol. 9, no. 16, p. 18, 2019. https://doi.org/10.3390/educsci9010016

[17] B. A. Oakley, D. M. Hanna, Z. Kuzmyn, and R. M. Felder, "Best Practices Involving Teamwork in the Classroom: Results From a Survey of 6435 Engineering Student Respondents," *IEEE Transactions on Education,* vol. 50, no. 3, pp. 266–272, 2007. https://doi.org/10.1109/TE.2007.901982

[18] A. Gero, "Development of Interdisciplinary Lessons Integrating Science and Engineering in Heterogeneous Teams: Education Students' Attitudes." *International Journal of Engineering Pedagogy (iJEP)*, vol. 6, no. 2, pp. 59–64, 2016. https://doi.org/10.3991/ijep.v6i2.5683

[19] R. Salim, M. Abdullah, H. N. Haron, N. H. Hussain, and R. Ishak, "A Team-Teaching Model in an Informal Cooperative Learning Classroom." *International Journal of Emerging Technologies in Learning (iJET)*, vol. 14, no. 20, pp. 44–57, 2019. https://doi.org/10.3991/ijet.v14i20.11458

[20] R. Tucker and N. Abbasi, "Bad Attitudes: Why Design Students Dislike Teamwork." *Journal of Learning Design,* vol. 9, no. 1, 2016. https://doi.org/10.5204/jld.v9i1.227

[21] P. Appiah-Kubi, "Multivariate Analysis of Students Perception on Teaching with Client Based and Non-Client Based Team Projects." *International Journal of Engineering Pedagogy (iJEP)*, vol. 8, no. 3, pp. 93–103, 2018. https://doi.org/10.3991/ijep.v8i3.8498

[22] P. Bychkov, I. Zabrodina, M. V. Netesova, and C. Mapelli, "Game-Based Learning while Research Activities of Engineering Students." *International Journal of Engineering Pedagogy (iJEP),* vol. 8, no. 4, pp. 153–161, 2018. https://online-journals.org/index.php/i-jep/article/view/8126

[23] M. Vodenicharova, "Gamed-based Learning in Higher Education." *TEM Journal,* vol. 11, no. 2, pp. 779–790, 2022. https://doi.org/10.18421/TEM112-35

[24] Novák, “The Term Project Method of Teaching and Its Interpretation.” In *Schola nova, quo vadis? 2016, Reviewed Papers of the International Scientific Conference, Prague, Czech Republic,* pp. 127–133, 07 November 2016.

[25] D. Orbánová and Ľ. Velichová, “Implementation of Project Learning into Teaching Practice.” In *Sapere Aude 2013: Pozitivní vzdělávání a psychologie, Reviewed Proceedings of the 3rd International Scientific Conference.* Czech Republic: Hradec Králové, vol. 3, pp. 254–260, 25–29 March 2013.

[26] Z. Chmelárová and A. Čonková, “Project Based Learning from the Point of View of Economics Students.” *TEM Journal,* vol. 10, no. 2, pp. 832–838, 2021. https://doi.org/10.18421/TEM102-42

[27] I. de los Ríos Carmenado, B. F. Rodríguez, and F. G. Gajardo, “Methodological Proposal for Teamwork Evaluation in the Field of Project Management Training.” *Procedia – Social and Behavioral Sciences*, vol. 46, pp. 1664–1672, 2012. https://doi.org/10.1016/j.sbspro.2012.05.358

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PAPER

Project-Based Learning: Authentic Engineering Assessment Supported by Model Design

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ABSTRACT

In this study, we examined the effects of project-based learning (PBL) on student learning outcomes related to the subject of signals and systems in the field of electronic engineering at the Universidade Estadual de Campinas (UNICAMP) in Brazil and at the Pontificia Universidad Javeriana (PUJ) in Colombia. We used two methods to assess the effect of PBL on student outcomes: (1) we used the Signals and Systems Concept Inventory (SSCI) to measure the increase in conceptual understanding of signals and systems among electronic engineering UNICAMP students as a consequence of implementing PBL; and (2) we compared the results on a comprehensive signals and systems final exam of a group of electronic engineering students at PUJ who received PBL to those who did not. Results indicated that (1) UNICAMP students achieved outcomes comparable to those of Buck and Wage's study: UNICAMP students taught with projects learned more than students in 15 *Signal and Systems* lecture-based courses in the United States; and (2) PUJ students taught with projects received higher final exam grades than students taught via lectures. Students were able to apply their knowledge of signal processing and systems analysis using MATLAB models. These models provide authentic assessments of engineering students' knowledge and skills. The findings of this study indicate that PBL is more effective than lectures in enhancing students' understanding and application of signals and systems concepts.

KEYWORDS

project-based learning, authentic assessment, mathematical modeling, learning outcomes, signals and systems engineering

1 INTRODUCTION

Courses in engineering education are usually theoretical and offer limited possibilities for applying disciplinary concepts. This is frequently the case with *Signals and Systems*, a subject taught as part of the electronic engineering program in the third year at UNICAMP and PUJ. Content is taught in lectures in which the instructor

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explains a topic and students take notes in class. Students frequently present difficulties in understanding some concepts and how to apply them.

Signals and systems is a field of study that involves examining the representation of signals and the changes that occur to them as they pass through systems. Signals and systems have many applications in engineering, including electrical and electronic circuit design, photonics, electromagnetics, telecommunication systems, control systems, and electrical power systems. Thus, it is studied in electronic engineering and other fields such as mechatronics, bioengineering, networks, and telecommunications.

The study of signals and systems is highly mathematical because the focus is on predicting the behavior of a system when it is subjected to different input signals. Students often struggle to appropriately apply the mathematical content required to understand the operation of signals and systems. In surveys carried out with students, one of the recommendations they made to help them understand the content of the course was that students should be required to carry out exercises and applications to be able to "see a signal in the real world" and not just solve mathematical problems. To do this, we set up a series of projects to encourage students to use the ideas they learned in class. Students can also work together to solve problems and learn about them through the projects.

MATLAB, a program for designing, developing, and evaluating solutions, was used to create the projects. MATLAB is a numerical calculation and programming platform used for data analysis, algorithm development, and model creation. Students can use MATLAB to apply mathematical concepts and models to the operation of signals and systems. The program is used in various industries, including the automotive, medical devices, biotech, pharmaceutical, and communications industries [1].

1.1 Project-based learning

Project-based learning (PBL) is used in engineering education to help students achieve learning outcomes [2–5]. PBL is a teaching method in which students improve their understanding of a subject through the completion of meaningful projects and product development [6]. Díaz-Barriga [7] proposed five characteristics of the PBL: (1) it involves focusing on a learning outcome of the curriculum; (2) it is a strategy facilitated by the teacher, and the student actively and purposefully participates; (3) it promotes the learning of knowledge and procedures of project management and collaboration between students; (4) it provides a set of tasks in which all students can participate; and (5) it is oriented toward a specific product. The creation of a concrete product is what differentiates this strategy from problem-based learning [8].

Prince and Felder [9] investigated the distinctions between various teaching methods such as inquiry-based learning, problem-based learning, PBL, and case-based learning. These authors emphasized that all these teaching methods share certain characteristics, such as being student-centered, in the sense that they involve seeking to encourage students to actively participate in their learning. They are all constructivist approaches; that is, they involve assuming that students construct their own understandings of a subject rather than absorbing information presented by their instructors. Similarly, all these methods involve students discussing answers to questions, solving problems, and working collaboratively.

However, Prince and Felder argued that, although the methods are very similar, differences can be found in that the product of inquiry-based learning can simply be the answer to an interesting question: case-based learning involves the analysis of real or hypothetical cases, PBL involves developing a product (which can be a design, a model, an apparatus, a physical product, or a computer simulation), and problem-based learning is characterized by presenting students with ill-defined problems that do not have clear goals, solution paths, or expected solutions. Thus, students participate in the definition of the problem. These authors mentioned that PBL requires the application of previously-acquired knowledge while problem-based learning requires the acquisition of new knowledge, and that the solution may be less important than the knowledge gained in finding the solution.

1.2 Authentic assessment

Authentic assessment enables students to apply theoretical and procedural content to real contexts, like those of their professional practice or daily life, creating a link between what is learned and the contexts where learning occurs. Authentic assessment involves assigning complex or challenging tasks to students that enable instructors to provide frequent feedback on their learning process. In addition, real-life situations usually involve interaction with others, which is why authentic evaluation includes situations of social interaction and positive interdependence [10].

Authentic assessment is inherent to the learning process. Therefore, it cannot be disjointed from teaching methods. For example, transmissive lectures are evaluated through multiple-choice questions that are used to assess how well students memorized the concepts presented in class [11]. Thus, PBL is assessed through the creation of products, designs, models, or simulations, which enables students to demonstrate that they can apply theoretical and procedural knowledge to signal processing and systems analysis, which are authentic performance contexts for engineers.

MATLAB supports the creation of student designs, models, and simulations and enables users to perceive the effects of model variations on signal processing. Students are free to experiment, explore, and discover the implications of the variations of their models in MATLAB. The program has many applications in image processing, computer vision, wireless communications, data science, control systems, robotics, and many others [12].

1.3 Previous investigations

Few articles have been published on the use of PBL in higher education. Researchers who conducted a literature review of PBL in higher education found that only 76 of the 450 studies published before September 2019 met criteria such as: (1) the studies had to be empirical and should provide original data; (2) the studies had to focus on student learning; (3) the implementation of PBL had to be conducted in higher education; (d) the impact of PBL on student learning outcomes had to be measured; (e) the studies had to meet the key characteristic of PBL, namely the development of a product. Furthermore, only 17 of these 76 articles contained evaluations of disciplinary knowledge acquisition, and only 9 evaluated disciplinary skill acquisition [13]. Also, other researchers performed a meta-analysis to compare the effects of PBL with traditional methods of instruction. Only 29 articles published between 1998 and 2017 reported medium to large positive effects on students' academic achievement compared with traditional instruction [14]. Only 6 of those 29 articles contained investigations of the effects of PBL on learning outcomes in higher education.

Between 2000 and 2019, the effects of PBL on engineering education were studied in 73 published articles, 32 documents presented at conferences, and three book chapters [15]. Among these investigations, only 45 involved the use of a quantitative methodology, and only 16 specifically covered PBL in electronic engineering. Likewise, most articles involved studying the implementation of PBL in a course (N = 73), and only a few involved doing so at the curricular level (N = 23).

Several scholars reported that PBL increased students' content knowledge, use of cognitive learning strategies, motivation, self-efficacy, engagement, and skills, including critical thinking, collaboration, lifelong learning, and artifact performance [13]. The authors of another review focused on examining different forms of implementation and the challenges involved in PBL. These authors identified common patterns in the implementation of PBL, such as students working in small groups to solve unstructured, authentic problems. Additionally, these authors found that PBL implementation can be hindered by heavy workloads, limited time and resources, and a lack of pedagogical training for both students and teachers. In contrast, having institutional support for resources, promotion standards, infrastructure, and learning equipment were factors that facilitated the method's implementation [15]. Lastly, the authors of a meta-analysis showed that PBL is more effective than lecture-based instruction and investigated the factors that can moderate the effect of PBL on student outcomes, such as group size, hours of instruction, and information technology support [14].

According to this literature review, this study particularly contributes to the knowledge of the use of PBL in engineering. As mentioned above, few researchers have analyzed the impact of this teaching method on student learning outcomes (i.e., knowledge and skills) in engineering education [13–15].

1.4 Research question

The primary research question in this study is whether PBL improves students' understandings of signal and system concepts. Therefore, we developed specific project assignments that can be used to improve students' understandings of signals and systems concepts. The research objectives were to (1) evaluate how well students learned signals and systems concepts using specific projects designed for the *Signals and Systems* course, and (2) compare the learning outcomes of students using PBL versus traditional instruction.

2 DESCRIPTION OF THE COURSE AND PROJECTS

In the *Signals and Systems* course at UNICAMP and PUJ, signals are studied, and a signal is understood as anything that contains information about the nature or behavior of some physical phenomenon (e.g., an electromagnetic, acoustic, mechanical, and biological phenomenon) [16]. Systems use signals as inputs to generate specific outputs. For example, electronic systems can capture acoustic information, encode it as a signal, process it, and produce an output as an acoustic signal again (like when we communicate on a telephone).

A signal can be mathematically represented by means of a function that depends on one or more independent variables. In *Signals and Systems*, two types of signals are studied (i.e., continuous and discrete signals), each with its own characteristics and classifications. The mathematical functions for calculating continuous and discrete signals are the following:

$$x(t) = 0.5\cos(2\pi 100\, t) - 0.3\sin(2\pi 150\, t) + 0.1\cos(2\pi 250\, t) \quad (1)$$

$$x[n] = 0.5\cos(2\pi 100\, n) - 0.3\sin(2\pi 150\, n) + 0.1\cos(2\pi 250\, n) \quad (2)$$

Figure 1 depicts the signal's continuous-time x(t) graphic representation and a discrete-time signal x[n] graphic representation of a segment of a human voice.

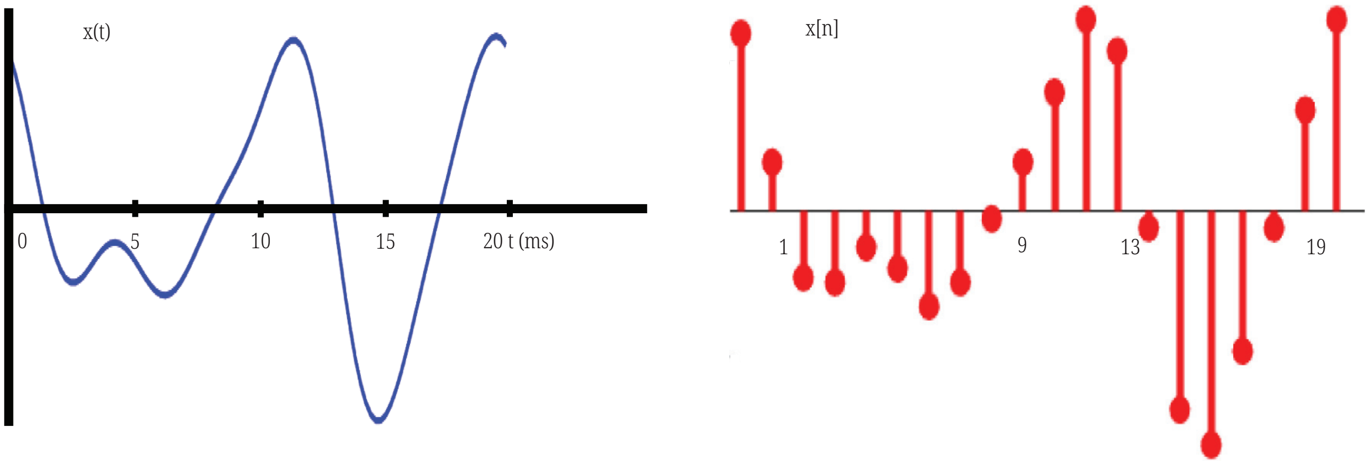

Fig. 1. Graphical representation of a signal's continuous-time x(t) and a discrete-time x[n] segment of a human voice

In addition, students study linear time-invariant (LTI) systems in the *Signals and Systems* course. These systems are those that comply with the properties of linearity and invariance in time [17]. LTI systems are important because they facilitate the analysis of complex systems that can be represented by mathematical models that meet these two conditions. Their practical utility lies in the fact that when the impulse response of a system is known, the output from any input can be known. For example, in the analysis of the acoustics of a theater, or by means of filters, the amplitude of unwanted signals can be reduced until they are almost imperceptible. Finally, in the course, students study the sampling process of a continuous signal and the conditions under which it is possible to recover this sampled signal.

Systems analysis, combined with system interactions, enable students to describe and analyze the behavior of LTI systems that are used in a variety of contexts, including control systems (e.g., the control system of a robot), communication systems (e.g., communication via telephones), digital systems (e.g., computers), medicine (e.g., signals from the brain), and bioengineering (e.g., reading and monitoring the insulin level of a diabetes patient).

Sound processing is one of the most common applications of signal analysis. In Project 1, students can perform different types of time transformations (e.g., inversion, scaling, and delay sequence) on an audio signal to understand their effects. For example, students can use inversion to play an audio clip of a human voice saying the palindrome, "A man, a plan, a canal: Panama" in reverse at different speeds (i.e., perform scaling) until it sounds correct. Delay is commonly used to produce an echo effect on voices. It has been used by artists such as Elvis Presley and U2.

Sound processing can also involve the use of LTI systems. For example, this can be done to combine a singer's voice with an instrument, as Cher does in her song "Believe." Another useful application of LTI systems is in the analysis of the effect of performing in an auditorium. LTI systems also have applications in image processing, such as image sharpening (i.e., reconstructing signals). In Project 2, the impulse response of the LTI systems is used so that the output can be determined from any input using convolution or by combining two signals to generate a third signal.

The Fast Fourier Transform (FFT) algorithm must be used in Project 3 to identify the frequencies generated by pressing a digit on a telephone keypad. When we use a landline phone and dial different numbers, DTMF value identification can be used to recognize the numbers on the target device or the information we want to convey through the phone keypad (e.g., the input of menu options or a credit card number). In this project, students must identify a series of 15 tones generated by pressing the number pad on a telephone in an audio recording. Specifically, they must identify the numbers that were pressed and the order in which they were dialed.

In Project 4, students design an LTI filter to recover the original message from a noisy voice message. In this project, students are given an audio file of a song that has noise added to it. Students must determine the bandwidth of the noise and design a filter that makes the noise imperceptible to the listener while maintaining the song's sound.

The effects of sampling and subsampling on signal visualization are investigated in Project 5. We hope that by completing this project, students can visualize the effects of sampling and subsampling and, thus, comprehend the Nyquist theorem, which describes how to sample a signal so as not to lose information. Any signal containing frequencies higher than those established by Nyquist cannot be reconstructed to its original state. If the signal contains lower frequencies than those established by Nyquist, then the original signal can be reconstructed.

In this project, the students must change the drip rate of a small hose. Students start with a fixed drip frequency and then increase the frequency or speed to see what happens when a signal is under-sampled without meeting the Nyquist conditions. The water may appear to go upward when observed on the screen of a mobile phone, but in real life, the water will always be seen falling. The first four projects are done using MATLAB. The fifth project does not necessitate the use of MATLAB, but a cellphone is needed.

The characteristics of the five projects mentioned above are described in Table 1.

Table 1. Expected learning outcomes, activities, and evaluations of the projects

Expected Learning Outcome	Learning Activities	Evaluation
Project 1: **Apply transformations of the independent variable to audio signals.**	Create the variables corresponding to the audio files in MATLAB. Specify the time variable for each audio file. Perform the transformations of displacement, inversion, and scaling on the audio files.	The student will produce different audio files with different sound effects (i.e., shift, reverse, and scale) from the input audio signal.
Project 2: **Find the impulse response of an LTI system in a physical system.** **Use the convolution of this system's impulse response with an input to an LTI system to identify the produced signal.**	Calculate the impulse response of a real system. Use MATLAB to calculate the convolution between the system's input signal and its impulse response.	The student will simulate the output signals of different LTI systems based on their impulse responses and input signals, identifying the perceptual differences between the input and output signals.
Project 3: **Use the FFT to identify the frequencies that make up a signal.**	Segment the input signal from the identified sounds. Apply the FFT to each of the audio segments. Identify the two main frequency components of each audio segment. Do the mapping between the two main frequencies of each segment and the numbers on the telephone keypad.	The student will design a model to analyze the input signal from the frequencies that compose it. The model indicates the input order of each of the 15 digits in the audio file.
Project 4: **Identify the parameters that a filter must meet to obtain the desired audio when applied to the input signal.** **Design a couple of digital filters (i.e., finite impulse response and infinite impulse response) that reduce the noise added to a song.**	Identify the frequency interval in which the frequency sweep to be eliminated is located. Use the Filter Designer Tool in MATLAB to create the corresponding filter. Apply the designed filter to the signal to be filtered.	Students will create a pair of digital filters that will allow them to listen to a song with low noise levels.
Project 5: **Compare the result of a sampled signal when the Nyquist sampling rate is met and when it is not met.**	The student should run a rubber hose down past a speaker so that the hose touches the speaker. When the speaker produces sound (i.e., vibrates), it will vibrate the hose. Students let the water run and record the flow rate. While the student is recording, they should change the frequency of the speaker's vibrations and watch what happens to the water flow on camera.	The student will make a video to record the water flow and explain the activity. The student will present a model that explains the frequency interval when the water flow is observed moving upward on a mobile phone screen.

The students received continuous feedback throughout the duration of their projects based on the requirements of each assignment. Students can determine which criteria they met and did not meet through formative assessments. The formative assessments also assisted instructors in identifying student areas of difficulty and immediately addressing them. At the conclusion of the project, each group was informed of their most significant achievements. Exemplary outcomes were demonstrated in class. This is done to not only highlight results that exceeded expectations but also inspire other students to make future achievements.

3 MATERIALS AND METHODS

3.1 Research design

We used two methods to test the effectiveness of the implementation of PBL in *Signals and Systems*: normalized gain scores [18] and a quasi-experimental design using a nonequivalent control group post-test only [19]. Students in a signals and systems course at UNICAMP that involved the use of the PBL method were tested before and after the course to assess their gains in conceptual understanding as a result of instruction. In addition, the students in the same course at PUJ were tested the semester before the implementation of PBL techniques and the semester after the implementation of those techniques.

3.2 Subjects

A total of 19 electronic engineering students from UNICAMP participated in this study. The students were juniors, between 20 and 33 years old (on average, 22 years old), and the group was made up of 14 men and 5 women.

In addition, 26 students from PUJ's electronic engineering program who took a *Signals and Systems* course in which PBL was used participated in this study. The students were juniors, aged 19 to 21 (20 years on average), and there were 22 men and 4 women in the group. These students' final exam results were compared to those of the 19 students who took the same course with the same teacher and took the same final exam in the previous year.

3.3 Research instrument

The SSCI is a 25-question, multiple-choice exam designed to assess students' understandings of the fundamental concepts taught in the *Signals and Systems* undergraduate course that is part of the electronic engineering curriculum [20]. When administered before and after the completion of the course, the SSCI measures the gain in a student's conceptual understanding as a result of instruction. Information about the validation of the instrument can be found in the article by Buck et al. [20].

In addition to supporting research on the impact of course-specific instruction on students' understandings of fundamental signals and systems concepts, the SSCI facilitates comparisons between universities and different populations.

3.4 Data analysis

The SSCI makes it possible to obtain a quantitative assessment of student performance. When administered as a pre-test and post-test, it can be used to quantify how much students have learned in a course. For this purpose, the normalized gain is obtained as follows:

$$\langle g \rangle = \frac{post - pre}{100 - pre} \tag{3}$$

The pre-test and post-test values are calculated using only the grades of students who took both exams. The normalized gain represents a fraction of the progress achieved in the course. Another interpretation is that students learn 100$\langle g \rangle$% of the concepts that they did not know before taking the course.

In addition, PUJ students' final exam scores were analyzed using a Shapiro–Wilks test to determine whether the data were normally distributed. The Shapiro–Wilks test is best suited for use in studies with small sample sizes (i.e., less than 50 participants). The Shapiro–Wilks test results indicated that the samples were normally distributed (for the control classroom, W (19) = 0.94, p = 0.23, and for the PBL classroom, W (26) = 0.96, p = 0.43). The Levene's test results, on the contrary, revealed unequal variances (F (1,43) = 8.38, p = 0.01). Thus, a Welch test was used to test the differences between group means.

4 RESULTS

4.1 SSCI results for UNICAMP students

Table 2 shows the normalized SSCI gain obtained by UNICAMP students due to the implementation of PBL.

Table 2. SSCI results

Student	First Week (PRE)	Last Week (POST)	Gross Gain	Normalized Gain
1	80	92	12	60
2	64	68	4	11
3	36	56	20	31
4	40	48	8	13
5	52	80	28	58
6	32	68	36	53
7	52	64	12	25
8	40	72	32	53
9	52	68	16	33
10	80	92	12	60
11	32	76	44	65
12	40	60	20	33
13	52	56	4	8
14	52	80	28	58
15	48	72	24	46
16	56	76	20	45
17	32	52	20	29
18	48	64	16	31
19	40	44	4	7
Mean	49	68	19	38

Additionally, a Welch test was performed to evaluate the effect of instruction on the SSCI score. The analysis revealed a significant difference between pre-test and post-test results ($t(35.88) = 4.24$, $p = 1.47$). On average, students scored higher after PBL instruction than before. These results support the conclusion that students gained knowledge in signals and systems through instruction.

Table 3 shows the mean results of the pre-test and post-test and the normalized SSCI score gain for the UNICAMP students.

Table 3. Comparison of pre and post means and medians, and normalized gain SSCI scores for UNICAMP students

	N	Mean	Median	Standard Deviation	Minimum	Maximum
Pre-test	19	48.84	48	14.15	32	80
Post-test	19	67.79	68	13.36	44	92
Gain		0.38	0.33	0.19	0.07	0.65

Buck and Wage [21] calculated the normalized gain for 20 signals and systems courses. Lecture courses had an average normalized gain of $\langle g \rangle = 0.20 \pm 0.07$ while the five courses that involved the use of an active and cooperative teaching strategy achieved an average normalized gain of $\langle g \rangle = 0.37 \pm 0.06$. The results of this study align with those in Buck and Wage's study because we obtained an average normalized gain of $\langle g \rangle = 0.38 \pm 0.19$ when comparing the pre- and post-test results of the students at UNICAMP (see the results in Table 3).

4.2 Final exam results for the PUJ Students

In the PUJ course, the students from the semesters before and after the implementation of the PBL took the same final exam. The final grades can vary from 0 to 5. Table 4 shows that the mean final exam grade was higher for the students who carried out the projects: 2.30 for the course without projects and 3.06 for the course with projects. The standard deviation was reduced from 1.27 to 0.65. The minimum final exam grade also increased from 0.50 to 1.55.

Table 4. Comparison of final exam means and medians before and after PBL implementation

	N	Mean	Median	Standard Deviation	Minimum	Maximum
Course without projects	19	2.30	2.50	1.27	0.50	4.95
Course with projects	26	3.06	3.18	0.65	1.55	4.25
Difference	7	0.76	0.68	0.62	1.05	0.70

According to the Welch test, the difference in final exam averages between students who took the course without projects and those who took the course with projects is significant ($t(24.86) = 5.69$, $p = 0.025$). On average, students who took the course with projects scored higher than students who took the course before the projects had been included in it. The 95% confidence interval for the average final exam grade in the course with projects is between 2.80 and 3.32. These results support the conclusion that project-based teaching is more effective than lecture-based teaching for signals and systems content.

5 DISCUSSION

PBL is an effective teaching method for promoting student learning in electronic engineering signals and systems courses. The SSCI results for UNICAMP students indicate that those who developed signals and systems projects had a higher average normalized gain than those who were taught through lectures. In addition, according to the final exam results of PUJ students, the course in which the instructor implemented signals and system projects had, on average, higher grades. Therefore, PBL is more effective than lectures for teaching signal and systems related concepts and skills. Moreover, these outcomes are comparable to those of other universities in the world.

In an anonymous course evaluation, most of the students supported the PBL methodology, arguing that it was a more effective way of learning than lectures. Some of them also argued that they felt more motivated to study the signals and systems content in a course taught in this way. Some students suggested that this strategy should be incorporated into other courses. A negative aspect listed by some students was that this methodology is time-consuming.

Moreover, all students achieved the expected learning outcomes in each project. One reason students achieve the expected learning results is that in the application of theoretical concepts to the projects, they realized the conceptual deficiencies that they can solve with feedback from their peers or the instructor. In addition, as they use signals and systems concepts, they begin to widen their grasp of the procedures required to process a signal, consolidating their learning.

MATLAB also enables the integration of conceptual and procedural knowledge of signals and systems into sound or voice processing, which is an authentic performance context for an electronic engineer. "MATLAB projects allow me to deepen concepts and understand the use of signals and system concepts in real life," a student explained. The simulation carried out in MATLAB enables students to change the input and output variables and obtain different results. This means that students can try different strategies and approaches. The program also enables students to engage in simulating processes that, if carried out with the devices intended for them, would cause students to incur costs that must be considered because not all students have the means to do so beyond class. However, it is important to have resources and support students who have not used the program before or do not understand how to use it well.

Another issue to consider is that initially, students were fearful of developing the projects because they did not easily connect the theory seen in class with its application in the specific projects. However, throughout the project's development, students applied theoretical concepts and gained confidence that they could learn the course concepts. Furthermore, some groups proposed additional project parameters (such as user interface and real-time recording) in addition to those asked by the instructors because they believed they could improve the project.

Other researchers at a university in Taiwan found that PBL improved the self-efficacy of 45 engineering students [22] in a manner similar to that of our students, who acquired confidence in their ability to learn course concepts and proposed alternative project parameters. In addition, the students elaborated on their projects beyond what was initially required by their instructors by adding details, creating new meanings or interpretations, and refining their ideas through application. PBL has a positive effect on students' confidence in their ability to learn in a particular course, while also increasing their career aspirations [23]. It is particularly important to have at least one course in which PBL is implemented during the first four semesters of the degree because it positively affects the perception of students that they can obtain and hone career skills, increases their career aspirations, and helps students realize the importance of basic sciences and engineering courses for their careers.

In addition, the projects improved the motivation of the students and their involvement in the course. At the end of the course, we informally asked the students what they remembered the most from the course, and most mentioned the projects because they felt that they "were being engineers" when solving the problems. One reason PBL increases student motivation is that it puts them to work on real-life problems and enables them to observe the impacts of their actions on sound processing [24]. Similarly, other authors found that PBL promotes learning motivation among engineering students [22, 25, 26].

However, we first observed resistance to the teaching method among students who were accustomed to lectures. In addition, some students had conflicts working in groups and difficulties communicating with team members and managing "hijackers" of group work. This was also mentioned by other authors who have used this strategy [27–29].

The following strategy was implemented to reduce the likelihood of students dividing up projects throughout the semester. Groups were freely formed for the first project, but for the second and third projects, students were not permitted to work with students from their previous groups, and for the fourth project, students could freely choose their groupmates. One of the outcomes of implementing this strategy was that, in most cases, the group compositions from the first project did not coincide with those for the fourth project, despite the fact that students freely chose their groupmates in both cases. This is primarily due to the students' ability to meet people with whom they could work and find effective matches for them. They were also more likely to form fellowship relationships with members of the fourth group than members of other groups.

Teachers may be required to form groups that include both academically strong students and students who require additional support. This enables students to understand each other and, thus, creates positive interdependence between them [30]. The dissolution of the groups helped students get to know each other and served as an implicit admonition for those who did not work because they were not chosen for the new teams. The professor monitors the performance of the teams on a regular basis to answer academic questions and help team members get to know each other and evaluate each member's individual performance. Researchers have proposed various strategies for monitoring the individual performance of students on a team [30, 31].

From the instructor's point of view, the implementation of the methodology improves students' understandings of course concepts and procedures and their ability to utilize and apply their knowledge and encourages them to participate in class and ask complex questions. This is achieved because the following steps were followed in each project: (1) Each student must review the theoretical contents before class and, if necessary, review the MATLAB manual, (2) the objective of the project and its relationship with theoretical concepts are presented, (3) doubts about the program and tools that can be used are resolved (a student monitor supports students with the language and syntax used in MATLAB), and (4) the instructor answers students' questions.

Each project must be carefully planned. Therefore, the instructor must have time to define the project, create materials, and review and evaluate completed projects. It would be preferable to have a bank of projects that change from time to time so that students do not rely on the solutions from their senior classmates in the program. Similar considerations in the implementation of the PBL have been raised by other researchers [32].

6 CONCLUSIONS

The results of this study support the conclusion that project-based teaching is more effective than lectures in teaching signals and systems concepts. On the one hand, the normalized gain in knowledge and skills obtained by UNICAMP students (as measured on the SSCI) was greater than that obtained by the students in lecture-based courses at other universities. On the other hand, comparing the final exam grades for the PUJ *Signals and Systems* course taught by the same professor before and after the implementation of PBL techniques shows that, on average, the students who took the course with PBL obtained higher grades than students who took the course when the PBL techniques had not yet been implemented. These results are consistent for the two universities that participated in this study and with the results of the study by Buck and Wage [21] involving 20 courses at universities in the United States.

However, this study has some limitations. The first is the small number of participants at both universities: 19 at UNICAMP and 19 and 26 at PUJ. This limitation could lead to difficulties in generalizing the results. The second limitation is that we did not apply the same measurement instrument at UNICAMP and PUJ, which makes the results of the two universities not comparable. However, the final exam taken by PUJ students was designed by a professor with knowledge of the SSCI and the subject so that he could comprehensively measure students understanding of the fundamental concepts and skills pertaining to the subject of signals and systems. The third limitation is that a student's performance on a test can be explained by the student's prior knowledge, the student's motivation for the larger discipline, the student's learning habits, and the intervention itself. Given that this intervention cannot be randomized, the results of this study might be affected by the factors mentioned before.

Other practical implications of this study include the importance of institutional support for the implementation of PBL, such as giving faculty time to design, implement, and assess PBL with the assistance of instructional designers so that factors such as group size, group dynamics, student needs, and information technology support can be considered. In addition, the implementation of PBL in a course may be supported by curricular considerations regarding the implementation of the teaching method at different levels and the collaboration of faculty members from different courses within the program.

Finally, future research on the impact of the implementation of active teaching methods could benefit from the adoption of measures such as normalized gain to assess the impact of instruction to support decision-making about teaching methods. Hake [18] advocated using normalized gains because the measure differentiated between teaching methods and allowed for a consistent analysis over diverse student populations. International comparisons can lead to disciplinary consensus and reflection on the most effective teaching methods.

7 REFERENCES

[1] Mathworks. Available: https://www.mathworks.com/products/matlab.html [Accessed: April 10, 2023].

[2] A. Kolmos, F. K. Fink, and L. Krogh, *The Aalborg PBL Model: Progress, Diversity and Challenges.* Aalborg, Denmark: Aalborg University Press, 2004.

[3] M. Pinho-Lopes and J. Macedo, "Project-based learning to promote high order thinking and problem-solving skills in geotechnical courses," *International Journal of Engineering Pedagogy*, vol. 4, no. 5, pp. 20–27, 2014. https://doi.org/10.3991/ijep.v4i5.3535

[4] P. Taheri, "Project-based approach in a first-year engineering course to promote project management and sustainability," *International Journal of Engineering Pedagogy*, vol. 8, no. 3, pp. 104–119, 2018. https://doi.org/10.3991/ijep.v8i3.8573

[5] J. Uziak and V. P. Kommula, "Application of problem-based learning in mechanics of machines course," *International Journal of Engineering Pedagogy*, vol. 9, no. 1, pp. 68–83, 2019. https://doi.org/10.3991/ijep.v9i1.9673

[6] J. S. Krajcik and N. Shin, "Project-based learning," in *The Cambridge Handbook of the Learning Sciences,* R. K. Sawyer (Ed.), 2nd ed. Cambridge University Press, 2014, pp. 275–297. https://doi.org/10.1017/CBO9781139519526.018

[7] F. Díaz-Barriga, *Enseñanza situada: Vínculo entre la escuela y la vida*. México, D.F.: McGraw-Hill Interamericana, 2006.

[8] L. Helle, P. Tynjala, E. Olkinuora, and K. Lonka, "Ain't nothin' like the real thing. Motivation and study processes on a work-based project course in information systems design," *British Journal of Educational Psychology,* vol. 77, no. 2, pp. 397–411, 2007. https://doi.org/10.1348/000709906X105986

[9] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *Journal of Engineering Education,* vol. 95, no. 2, pp. 123–138, 2006. https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

[10] K. Ashford-Rowe, J. Herrington, and C. Brown, "Establishing the critical elements that determine authentic assessment," *Assessment & Evaluation in Higher Education*, vol. 39, no. 2, pp. 205–222, 2014. https://doi.org/10.1080/02602938.2013.819566

[11] J. T. Gulikers, T. J. Bastiaens, and P. L. Kirschner, "A five-dimensional framework for authentic assessment," *Educational Technology Research and Development,* vol. 52, no. 3, pp. 67–86, 2004. https://doi.org/10.1007/BF02504676

[12] Mathworks. Available: https://www.mathworks.com/products/matlab/data-analysis.html [Accessed: April 10, 2023].

[13] P. Guo, N. Saab, L. S. Post, and W. Admiraal, "A review of project-based learning in higher education: Student outcomes and measures," *International Journal of Educational Research,* vol. 102, pp. 1–13, 2020. https://doi.org/10.1016/j.ijer.2020.101586

[14] C. H. Chen and Y. C. Yang, "Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators," *Educational Research Review,* vol. 26, pp. 71–81, 2019. https://doi.org/10.1016/j.edurev.2018.11.001

[15] J. Chen, A. Kolmos, and X. Du, "Forms of implementation and challenges of PBL in engineering education: A review of literature" *European Journal of Engineering Education,* vol. 46, no. 1, pp. 90–115, 2021. https://doi.org/10.1080/03043797.2020.1718615

[16] A. Oppenheim, J. Buck, D. Michael, A. Willsky, S. Nawab, and A. Singer, *Signals & Systems*. New Jersey: Prentice Hall, 1997.

[17] S. Soliman and M. Srinath, *Continuous and Discrete Signals and Systems*. New Jersey: Prentice Hall, 1990.

[18] R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses," *American Journal of Physics*, vol. 66, no. 1, pp. 64–74, 1998. https://doi.org/10.1119/1.18809

[19] P. Krishnan, "A review of the non-equivalent control group post-test-only design," *Nurse Researcher*, vol. 26, no. 2, pp. 37–40, 2019. https://doi.org/10.7748/nr.2018.e1582

[20] J. Buck, K. Wage, T. Welch, and K. Wright, "The signals and systems concept inventory," *IEEE Transactions on Education*, vol. 48, no. 3, pp. 448–461, 2005. https://doi.org/10.1109/TE.2005.849746

[21] J. R. Buck and K. E. Wage, "Active and cooperative learning in signal processing courses," *IEEE Signal Processing Magazine*, vol. 22, no. 2, pp. 76–81, 2005. https://doi.org/10.1109/MSP.2005.1406489

[22] H. Kuo, Y. Tseng, and Y. Yang, "Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course," *Thinking Skills and Creativity*, vol. 31, pp. 1–10, 2019. https://doi.org/10.1016/j.tsc.2018.09.001

[23] M. Beier, M. Kim, A. Saterbak, V. Leautaud, S. Bishnoi, and J. Gilberto, "The effect of authentic project-based learning on attitudes and career aspirations in STEM," *Journal of Research in Science Teaching*, vol. 56, no. 1, pp. 3–23, 2019. https://doi.org/10.1002/tea.21465

[24] S. Reis, F. Coelho, and L. Coelho, "Success factors in students' motivation with project-based learning: From theory to reality," *International Journal of Online and Biomedical Engineering*, vol. 16, no. 12, pp. 4–17, 2020. https://doi.org/10.3991/ijoe.v16i12.16001

[25] H. Kuo, Y. C. Yang, J. Chen, T. Hou, and M. Ho, "The impact of design thinking PBL robot course on college students' learning motivation and creative thinking," *IEEE Transactions on Education*, vol. 65, no. 2, 124–131, 2022. https://doi.org/10.1109/TE.2021.3098295

[26] D. López-Fernández, L. Raya, F. Ortega, and J. J. García, "Project based learning meets service learning on software development education," *International Journal of Engineering Education*, vol. 35, no. 5, pp. 1436–1445, 2019.

[27] E. Bani-Hani, A. Al Shalabi, F. Alkhatib, A. Eilaghi, and A. Sedaghat, "Factors affecting the team formation and work in project-based learning (PBL) for multidisciplinary engineering subjects," *Journal of Problem-Based Learning in Higher Education,* vol. 6, no. 2, pp. 136–143, 2018.

[28] J. Dong and H. Guo, "Effective course redesign strategies to integrate collaborative PBL in senior computer engineering/computer science courses," in *121st ASEE Annual Conference & Exposition*, June 15–18, 2014, Indianapolis, IN, United States. https://peer.asee.org/effective-course-redesign-strategies-to-integrate-collaborative-pbl-in-senior-computer-engineering-computer-science-courses.pdf

[29] R. McQuade, S. Wiggins, E. Ventura-Medina, and T. Anderson, "Knowledge disagreement formulations in problem-based learning tutorials: Balancing pedagogical demands with 'saving face'," *Classroom Discourse*, vol. 9, no. 3, pp. 227–243, 2018. https://doi.org/10.1080/19463014.2018.1495089

[30] B. Oakley, R. M. Felder, R. Brent, and I. Elhajj, "Turning student groups into effective teams," *Journal of Student-Centered Learning*, vol. 2, no. 1, pp. 9–34, 2004.

[31] W. A. Friess and A. J. Goupee, "Using continuous peer evaluation in team-based engineering capstone projects: A case study," *IEEE Transactions on Education*, vol. *63*, no. 2, pp. 82–87, 2020. https://doi.org/10.1109/TE.2020.2970549

[32] J. L. Sanchez-Romero, A. Jimeno-Morenilla, L. M. Pertegal-Felices, and H. Mora-Mora, "Design and application of project-based learning methodologies for small groups within computer fundamentals subjects," *Institute of Electrical and Electronics Access*, vol. 7, pp. 12456–12466, 2019. https://doi.org/10.1109/ACCESS.2019.2893972

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PAPER

Deep Learning Influences on Higher Education Students' Digital Literacy: The Meditating Role of Higher-order Thinking

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ABSTRACT

Digital literacy has emerged as a core competency in the 21st century society, and deep learning and higher-order thinking have been discussed as effective ways to improve digital literacy. Therefore, this study aimed to verify the influence of deep learning and higher-order thinking skills on higher education students' digital literacy. Structural Equation Modeling was used to analyze the data gathered from 687 undergraduate and higher vocational students using a convenient sampling technique. The findings indicate that deep motivation and deep strategy were significantly positively correlated with students' digital literacy. In such a structural relationship, digital literacy was additionally moderated by higher-order thinking. Nevertheless, students who have customarily used digital devices for more than five years could not be explained by this structural equation model. Lastly, this conclusion highlighted that educators should consider students' digital experiences level, guide in selecting and applying deep learning, develop higher-order thinking, and improve their digital literacy.

KEYWORDS

digital literacy, deep learning, deep motivation, deep strategy, higher-order thinking

1 INTRODUCTION

Although education and technology have always been intertwined, as new digital technologies emerge, the education industry has recently encountered new opportunities and challenges. With the COVID-19 pandemic leading to mandatory online classes, teachers and students alike recognize the importance of digital literacy for effective online class participation [1], [2]. Therefore, higher education faces a significant challenge in developing students' digital literacy and meeting the needs of digital social development. Moreover, as digital natives, 75% of young people worldwide use digital information and only 63% in Asia-Pacific [3], so the level of digital literacy among students may vary and should be considered.

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Previous works of literature in the field of digital literacy have concentrated on the framework of digital literacy [4], [5], [6], the relationship between online learning and digital literacy [7], [8] [9], and how to improve digital literacy [10], [11], [12], [13]. More specifically, when increasing digital literacy, students also need to develop learning approaches [8], [14], motivation [15], [16], and critical thinking [17], [18].

In addition to improving digital literacy, fostering higher-order thinking among students of all academic levels was considered an important educational task [19], [20]. Higher-order thinking was described as critical thinking, creativity, collaboration, and communication (4C) [21], whereas digital literacy was characterized as operation skills and thinking skills [5]. Therefore, building higher-order thinking-based critical thinking abilities is crucial for developing digital literacy to classify information critically and create new knowledge [1], [22].

Moreover, a considerable number of studies found that deep learning was a powerful way to achieve the growth of higher-order thinking skills [23], [24]. For example, Nelson Laird et al. [23] selected three sub-scales from the National Student Engagement Survey (NSSE): reflection learning, integrated learning, and higher-order learning, and discovered that these three dimensions were consistent with the behavior of deep learning approaches. Nevertheless, the precise connection between deep motivation, deep strategies, and higher-order thinking remains unclear.

Previous literature has paid insufficient attention to the interrelationships between deep learning, higher-order thinking, and digital literacy although some researchers have explored the intersection of deep learning and digital literacy [8], [14] [25], deep learning and higher-order thinking [24], [26], [27], and higher-order thinking and digital literacy [1], [22], [28]. Few studies have considered the intersection of all three fields. Moreover, deep motivation and deep strategy are often studied as a whole, and whether the relationship between the two in higher-order thinking and digital literacy is consistent remains to be further studied.

This study aims to understand better the intersection between deep motivation, deep strategy, higher-order thinking, and digital literacy, which will help designers of higher education institutions, policymakers, and government agencies provide important insights to develop effective strategies to cultivate students' higher order thinking skills and digital literacy. Therefore, the following research questions served as the framework for this study:

1. Do students' deep motivation and deep strategy influence their digital literacy?
2. Does higher-order thinking play a mediating role in the influence of digital literacy?

2 LITERATURE REVIEW

2.1 Digital literacy

With the development of technology, literacy is also constantly developing, such as Internet literacy, media literacy, information literacy, ICT literacy, and digital literacy. Nevertheless, the term "digital literacy" was initially introduced by Gilster [5], who emphasized that individuals must be not only able to acquire information but also be able to evaluate and interpret it.

In exploring the framework of digital literacy, some scholars have argued that digital literacy comprises not only the skills and competencies required for Internet literacy, but also other components. For example, digital literacy covers a broad variety of complicated cognitive, physical, sociological, and emotional abilities that users require in a digital context. It goes beyond simply knowing how to utilize software or handle digital devices [4]. In addition, Ng [29] argued that digital literacy comprises three overlapping dimensions: technology, cognition, and social emotion.

In order to adjust to the evolution of education in the digital era and realize the sustainable and fair development of digital education, international organizations and various countries have taken a series of actions. For example, the European Union (EU) released the digital competency framework from 2013 [30] to 2022 version [2]. The 2022 framework divides digital competencies into five categories: information and data literacy, communication and collaboration, innovation, safety, and problem-solving.

2.2 Deep learning

Marton and Säljö [31] found that there are two main types of student engagement in the learning process: deep learning and surface learning. More specifically, deep learning is characterized by understanding and processing information, participating in high-quality activities, combining old and new knowledge, processing tasks, and solving problems. In contrast, surface learning is more likely to participate in low-level cognitive tasks and is less likely to create complicated associations between knowledge from books and real-world experiences.

Furthermore, Biggs [32] outlined three important learning approaches: deep, surface, and achieving, and pointed out the motivations and strategies involved in each learning approach. Deep motivation is the term for an individual's innate interest in the knowledge and abilities acquired in a particular field. In contrast, the deep strategy involves active and extensive reading, connecting with prior knowledge, and seeking to comprehend the underlying concepts and principles.

Previous studies have mostly concentrated on the association between deep learning and academic achievement [32], [33], [34]. However, more recent work examining deep learning has concentrated on the following: comparing deep learning with machine learning [35], examining the relationship between deep learning and higher-order thinking [26], [27], problem-solving [36], and digital literacy [8], [14].

2.3 Higher-order thinking

Higher-order thinking can be traced back to Bloom's [37] Taxonomy of the Cognitive Domain, which classified cognitive goals from lower-order to higher-order, including knowledge, comprehension, application, analysis, synthesis, and evaluation. Then, Anderson and Krathwohl [38] modified Bloom's Taxonomy and made several improvements: remembering, understanding, applying, analyzing, evaluating, and creating.

Studies on higher-order thinking are depicted differently. For example, Lewis and Smith [19] pointed out that higher-order thinking skills are the process by which a person associates new knowledge with information retained in memory and reorganizes it to achieve a specific goal or find possible responses to a difficult scenario. According to the classification of educational objectives as analysis, synthesis, assessment, and creativity, higher-order thinking refers to the mental activity or cognitive abilities formed at a higher cognitive level [39]. On the other hand, Yang and Zhao [20] classified remembering as lower-order thinking and understanding, applying, analyzing, evaluating, and creating as higher-order thinking according to Bloom's classification of educational goals.

Moreover, there are several methods and strategies for developing higher-order thinking in the classroom [17], [40]. For example, Reece [17] put forward that teaching should provide the following three stages to support the improvement of higher-order thinking: the first stage was the acquisition of skills; the next step was to incorporate the newly acquired knowledge and abilities into one's way of thinking; the third stage was to apply the combined skills to new situations. Moreover, Limbach and Waugh [40] offered a five-step strategy for fostering higher-order thinking, which included determining learning goals, teaching through inquiry, practicing prior to assessment, reviewing and improving, and providing feedback and learning evaluation. These five processes provided an easy way for educators to increase students' higher-order thinking skills.

2.4 The relationship among variables

Based on previous research, deep learning and information literacy are significantly positively correlated, and students' information literacy levels increase as they utilize deep learning more frequently [14]. However, students' performance largely depends on their level of motivation and how well they apply the appropriate learning strategies in the right situations [41], [42]. Moreover, Heinström [8] analyzed three information-seeking modes; fast surfing, broad scanning, and deep diving, and found that the deep strategy can motivate students to deep diving, achieving goals and leading to good results. In light of this, it is reasonable to assume that:

H1: Students' deep motivation contributes positively to their digital literacy.
H2: Students' deep strategies contribute positively to their digital literacy.

Based on the existing literature, it is evident that higher-order thinking and digital literacy are interrelated and have a reciprocal relationship [1], [22]. More specifically, digital literacy can enhance students' critical thinking and, eventually, learning based on higher-order thinking skills. Contrarily, critical thinking skills can increase students' digital literacy. Novitasari et al. [22] emphasized that higher-order thinking is important in building digital literacy. Consequently, it is reasonable to assume the following:

H3: Students' higher-order thinking contributes positively to their digital literacy.

Deep learning is a pedagogical approach that emphasizes using higher-order thinking skills to promote learners' acquisition of knowledge and skills [24], [26]. For example, Lee and Choi [26] surveyed 487 undergraduate students from seven South Korean universities and, using a structural equation model, concluded that promoting motivation and strategies can facilitate higher-order thinking in the background of a technologically advanced learning environment. Similarly, Wang and Cui [27] conducted a survey on 515 students of different majors and grades from six universities in northeast, north, east, south, and central China. The results showed that deep strategies significantly affect higher-order thinking skills. Hence, it is plausible to assume the following:

H4: Students' deep motivation contributes positively to their higher-order thinking.
H5: Students' deep strategies contribute positively to their higher-order thinking.

This research aimed to investigate the impact of deep motivation and deep strategies on students' digital literacy, with higher-order thinking serving as the mediating variable. Deep motivation is an individual's intrinsic interest in acquiring knowledge and skills within a particular domain. In contrast, deep strategies are defined as the selection of appropriate techniques and methods to design, train, and optimize learning. Higher-order thinking refers to the cognitive processes that involve complex mental skills such as analysis, synthesis, evaluation, and creativity to understand and solve problems. Digital literacy is characterized as encompassing not only technologies that use digital devices, but also cognitive, social, and emotional abilities. Figure 1 provides an illustration of the proposed model.

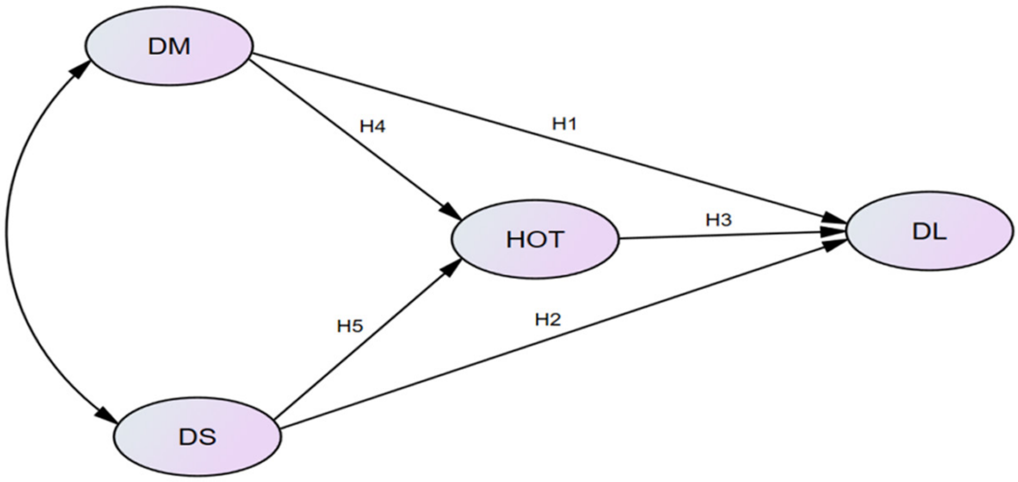

Fig. 1. Research model

Notes: DM, Deep motivation; DS, Deep strategy; HOT, higher-order thinking; DL, Digital literacy.

3 METHODOLOGY

3.1 Participants

The research survey was conducted during the first semester of the academic year 2022. The participants came from two different kinds of Chinese institutions: a regular university and a higher vocational college. Higher vocational colleges, encompassing vocational colleges, technical colleges, and higher vocational schools, refer to higher education institutions that primarily provide vocational and technical training to equip students with specialized skills and practical knowledge required to excel in specific trades or professions [43]. In contrast, regular universities prioritize theoretical knowledge and intellectual abilities to prepare students for successful careers. Because the first author and her colleagues are affiliated with these two institutions, the students were specifically chosen for the survey to facilitate the sampling process. Additionally, the study obtained ethical approval from both institutional review boards, and the researchers adhered to ethical principles while conducting research with human subjects.

The data collection process for this study was conducted during the Covid-19 pandemic lockdown period, when all educational institutions in China were closed. To overcome this challenge, an online survey was utilized to gather data, with voluntary participation. The survey was conducted in the following steps: Firstly, the researchers sought and obtained approval from multiple teachers for the study. Secondly, the teachers informed the students about the survey's purpose, duration, and nature of the information that would be collected. They also explained how the data would be collected, stored, and accessed, ensuring that no personal information would be disclosed in the survey. Lastly, the participants were directed to complete the survey on Questionnaire Star, a widely used platform for conducting online surveys.

During the study, the survey was available for a duration of two weeks, during which a total of 734 surveys were collected. To ensure the overall quality of the sample, the study followed two criteria. Firstly, surveys that were completed too quickly (in under five minutes) were considered invalid and consequently removed from the analysis. Secondly, the study excluded surveys from participants who exhibited straight-lining behavior, which refers to answering the questions in the same manner for most or all of the survey questions. Following the elimination of invalid surveys, the study retained 687 valid surveys, resulting in an effective response rate of 93.6%. These procedures were implemented to maintain the study's standards of rigor and ensure the reliability and validity of the collected data.

The majority of participants in the study were born after the 1990s, thus fulfilling Prensky's [44] criteria for being digital natives, defined as individuals born after the widespread adoption of digital technology. In terms of the student demographic information, there were 404 (58.8%) male students and 283 (41.2%) female students. In total, 349 of them (50.8%) came from an ordinary university, and 338 (49.2%) came from a higher vocational college. In the category of the academic year, 173 of them (25.2%) were freshmen, 272 (39.6%) were sophomores, 130 (26%) were juniors, and 112 (24%) were seniors.

As far as digital devices are concerned, 0% have none, 28.2% have 1 digital device, 36.8% have 2 devices, 21.6% have 3 devices, and 13.4% have 3 or more devices. Daily time spent on digital devices, 17 (2.5%) of less than 1 hour, 101 (14.7%) of 1–3 hours, 255 (37.1%) of 3–6 hours, and 314 (45.7%) of more than 6 hours. In terms of digital devices usage period, 373 people (54.3%) have used digital devices for less than 5 years, and 314 people (45.7%) have used them for more than 5 years. It is worth noting that according to the ITU [3], approximately 75% of individuals aged 10 and above own a mobile phone, and the digital device usage period refers to the duration between the initial and current usage of a digital device.

3.2 Measures

Digital literacy. Ng [29] developed the scale to explore undergraduate students' digital literacy. The original scale had 17 items with a Likert scale with a range of 1 (strongly disagree) to 5 (strongly agree). These items were divided into 4 categories: attitudes towards ICT for learning (DLA 7 items), technical (DLT 6 items), cognitive (DLC 2 items), and social-emotional (DLS 2 items). According to the result of factor analysis, 5 items from two dimensions were retained. The technical dimension included 3 items: DLT11 (knowledge of various technologies), DLT12 (ability to use ICT for learning and create artifacts that demonstrate comprehension), and DLT13 (proficiency in using ICT). The cognitive dimension included 2 items: DLC14 (confidence in evaluating online material) and DLC15 (awareness of web-based issues such as cyber safety, search problems, and plagiarism).

Deep learning. The Study Processes Questionnaire (SPQ) developed by Biggs et al. [45] was used to measure students' learning approaches. Moreover, the survey is split into two parts: deep learning and surface learning, each of which includes motivation and strategy. On a Likert scale with a maximum score of 5, deep motivation (DM 5 items) and deep strategy (DS 5 items) were adopted (such as "I believe that once I get into a topic, it may be really exciting to me"; "I find that studying academic issues may be just as interesting as reading a good book or seeing a good movie"; "I put myself to the test on crucial issues until I totally comprehend them"). Given that their factor loading was less than 0.5, item numbers DM4, DM5, and DS5 were eliminated from the items.

Higher-order thinking. Yang and Zhao [20], based on Bloom's [37] educational objective classification theory, made a comprehensive analysis of the concept, composition, and evaluation framework of college students' higher-order thinking skills. Combined with the actual situation of Chinese college students, 5 levels and 17 skills were adopted, including understanding (HOTU 7 items), applying (HOTAP 2 items), analyzing (HOTAN 3 items), evaluating (HOTE 2 items), and creating (HOTC 3 items). On the basis of the results of the factor analysis, three items of the analysis dimension and evaluating dimension are retained: HOTAN11 (I can distinguish relevant/important from irrelevant/unimportant information), HOTAN12 (I can draw systematic and internally consistent links between the information offered), and HOTE13 (I can evaluate and select solutions).

3.3 Procedures

The research consisted of three phases, with the preliminary phase focused on a pilot study aimed at improving the survey's quality. During the pilot survey, both reliability analysis and exploratory factor analysis were conducted. Items with poor internal consistency, as determined by a Corrected Item-Total Correlation (CITC) value less than 0.4, or a significant change in Cronbach's Alpha if Item Deleted (CAID) after item deletion, were removed. Additionally, items with factor loadings below 0.5 were eliminated. This process resulted in a refined set of scales with acceptable reliability and structural validity suitable for use in formal research.

In the second stage, the official survey was distributed through the online platform. The teacher of participants distributed a survey online link before class and informed the purpose of the survey. Moreover, the descriptive statistics, reliability, and correlation analyses were carried out using the SPSS 26 program. In addition, the structural equation model (SEM) was employed using Amos 26 program to analyze the direct and indirect interactions between variables.

Lastly, multi-group structural equation modeling was employed to test the research model's applicability to diverse groups. Specifically, the AMOS 26 program was used, offering six different models for conducting multi-group analysis. As Byrne [46] described, these models include the Unconstrained Model, Measurement Weights Model, Structural Weights Model, Structural Covariances Model, Structural Residuals Model, and Measurement Residuals Model. The Unconstrained Model allows for all parameters to vary among different groups. In contrast, the Measurement Weights Model requires the measurement weights parameters in the measurement model to be equivalent across groups. The Structural Weights Model restricts the equality of both the measurement weights and structural weights parameters across groups in both the measurement and structural models. Moreover, the latter models constrain the parameters of the former models. This study focused on examining differences in the path coefficients among different groups of students' digital device usage periods. Therefore, the Unconstrained Model, Measurement Weights Model, and Structural Weights Model were the models analyzed.

4 RESULTS

4.1 Reliability and validity

Firstly, internal consistency, convergent validity, and discriminant validity were utilized to assess the reliability and validity of the constructs in the measurement model. As a result, the construct reliability (CR) values varied from .746 to .913, and Cronbach's alpha coefficients were all higher than 0.7, showing acceptable levels of internal consistency for all variables. Moreover, except for deep motivation, the average variance extracted (AVE) values (from .618 to .770) were within an acceptable range. However, Fornell and Larcker [47] asserted that even if AVE is less than 0.5 but CR is greater than 0.6, a construct's convergent validity might still be considered suitable. Therefore, deep motivation's AVE value (.496) and CR value (.746) were also suitable (See Table 1).

Table 1. Measurement of constructs

Variables	Items	Loadings	Cronbach's Alpha	CR	AVE
Deep motivation	DM1	.730	.747	.746	.496
	DM2	.730			
	DM3	.650			
Deep strategy	DS1	.860	.860	.865	.618
	DS2	.850			
	DS3	.720			
	DS4	.700			
Higher-order thinking	HOTAN11	.890	.909	.909	.770
	HOTAN12	.910			
	HOTE13	.830			
Digital literacy	DLT11	.780	.912	.913	.677
	DLT12	.830			
	DLT13	.860			
	DLC14	.800			
	DLC15	.840			

Moreover, discriminant validity was examined to ensure that all of the variables (deep motivation, deep strategy, higher-order thinking, and digital literacy) were distinct from one another. The square root of each variable's AVE value should be bigger than all of the correlation values of the variable [47]. Hence, the square root of AVE values for each variable was shown in Table 2, which were larger than the other correlation coefficients between the variables. Therefore, Tables 1 and 2 demonstrate the structure has high reliability and validity.

Table 2. Discriminant validity

Variables	DM	DS	HOT	DL
DM	.704			
DS	.510	.786		
HOT	.350	.350	.877	
DL	.420	.420	.640	.823

4.2 Correlation analysis

Table 3 displayed all the research variables' Means, Standard Deviations (SD), Skewness, Kurtosis, and Correlation coefficients. The mean values varied from 2.676 to 3.651, with SD ranging from .734 to 1.103. In addition, the normality of the variables was examined using Skewness and Kurtosis. As a multivariate normal distribution, all variables met Skewness < 2 and Kurtosis < 7 [48]. Consequently, the variables were considered appropriate for structural equation modeling (SEM) analysis. Moreover, according to the correlation analysis results, there was a significant relationship between all the research variables below the significance level of .001.

Table 3. Correlation analysis and descriptive statistics (N = 678)

Variables	DM	DS	HOT	DL
DS	.423***			
HOT	.304***	.313***		
DL	.353***	.377***	.589***	
Mean	2.704	2.676	3.651	3.450
SD	.918	1.103	.806	.734
Skewness	.264	.146	.025	.072
Kurtosis	–.097	–.746	–.292	.321

Note: ***p < .001.

4.3 Hypothesis analysis

The results revealed a good structural model fit with χ^2/df = 2.35, CFI = .98, GFI = .96, TLI = .98, and RMSEA = .04. As a result, the proposed model suited the empirical data well. Furthermore, Table 4 showed that the five proposed relationships and the structural model were significant in the predicted direction. As a result, all of the suggested hypotheses were accepted.

According to the research results (See Figure 2), deep motivation (β = .160, p < .001) and deep strategy (β = .150, p < .001) both had a direct effect on digital literacy. Thus, hypotheses 1 and 2 were accepted. In addition, higher-order thinking significantly influenced digital literacy (β = .530, p < .001), demonstrating that hypothesis 3 was also accepted. Hypotheses 4 and 5 were prepared to distinguish the direct effect of deep motivation and deep strategy on higher-order thinking. The results showed that both deep motivation and deep strategy support the improvement of higher-order thinking, and that deep motivation's influence ($\beta = .240$, $p < .001$) was stronger than deep strategy's ($\beta = .220$, $p < .001$). Therefore, hypotheses 4 and 5 were also approved.

A bootstrapping method (2000 samples) was used for mediation analysis, bias-corrected confidence estimates, and 95% confidence intervals for indirect effects to examine the influence of deep motivation and deep strategy on digital literacy. As shown in Table 5, higher-order thinking was mediated between deep motivation and digital literacy. The indirect effect value was .110 (SE = .030, Bias-corrected 95% CI = [.060, .170]) and the confidence interval did not contain 0, and p < .001. Higher-order thinking was mediated between deep strategy and digital literacy. The indirect effect value was .080 (SE = .020, Bias-corrected 95% CI = [.040, .120]) and the confidence interval did not contain 0, and p < .001.

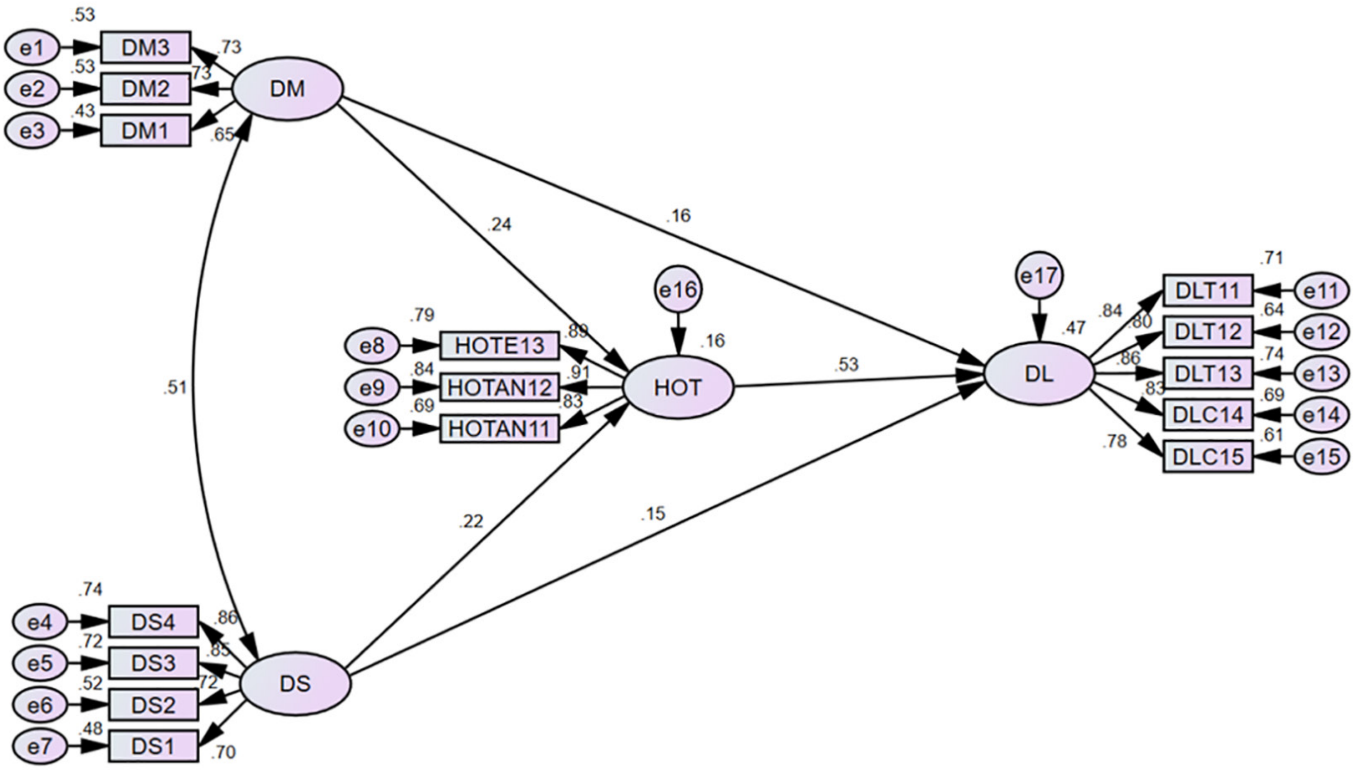

Fig. 2. Path diagram and standardized estimate

Table 4. Results of the hypothesis test

Hypotheses	Path	β	B	S.E.	C.R.	P	Testing Result
H4	DM → HOT	.240	.210	.050	4.380	<.001	Support
H5	DS → HOT	.220	.150	.030	4.380	<.001	Support
H1	DM → DL	.160	.140	.040	3.420	<.001	Support
H2	DS → DL	.150	.100	.030	3.610	<.001	Support
H3	HOT → DL	.530	.510	.040	13.500	<.001	Support

Table 5. Mediating effects of bootstrapping

Path	Point Estimate	Product of Coefficients		Bootstrap 2000 Times 95% CI Bias-Corrected		
		SE	*Z-Value*	*Lower*	*Upper*	*P*
DM → HOT → DL	.110	.030	3.667	.060	.170	<.001
DS → HOT → DL	.080	.020	4.000	.040	.120	<.001

4.4 Multi-group comparison analysis

This study applied a multi-group analysis to compare the path coefficients of the students' digital devices usage period. The samples were divided into groups of less than five years and more than five years, and the two groups' structural equation models were constructed. Table 6 provides the fit indices for the Unconstrained Model, Measurement Weights Model, and Structural Weights Model. It is evident that all of the indicators satisfied the model fitness requirements. The comparison of the fit indices between the Measurement Weights Model and Structural Weights Model showed that it was lower than .050, indicating a significant difference in the path coefficients between the two models ($\Delta\chi^2 = 13.210$, and $\Delta p = .020$).

Table 6. Fit indices of the multi-group analysis model by digital devices usage period

Model	χ^2	χ^2/df	P	TLI	CFI	RMSEA
Unconstrained	301.760	1.800	.000	.970	.980	.030
Measurement Weights	310.400	1.730	.000	.970	.980	.030
Structural Weights	323.600	1.760	.000	.970	.980	.030

As shown in Table 7, the five path coefficients of the two multi-group models were compared. The critical ratios for differences determined the specific differences between the parameters. If the critical ratio for the two corresponding paths is above 1.96, the parameter difference is significant [46]. The two path coefficients were significantly different (from deep strategy to higher-order thinking).

Table 7. Critical ratio value of parameter difference in digital devices usage period

Path	a1	a2	a3	a4	a5
b1	1.710				
b2		–2.740			
b3			.850		
b4				.470	
b5					1.150

Notes: a = less than 5 years; b = more than 5 years; a1 and b1: DM → HOT; a2 and b2: DS → HOT; a3 and b3: HOT → DL; a4 and b4: DM → DL; a5 and b5: DS → DL.

Further analysis was conducted on the significantly different path coefficients, and the results were given in Table 8. In the group of 'less than five years', the standardized path coefficient of deep strategy to higher-order thinking is .340, and $p < .001$, while in the group of 'more than five years', the standardized path coefficient is .060, and $p = .380$. Therefore, higher education students with less than five years of digital device usage can better improve higher-order thinking with deep strategies. However, the finding also revealed that deep strategies are not a predictor of higher-order thinking for students with more than five years of digital device usage.

Table 8. Standardized coefficient of path

Path	Digital Devices Usage Period	β	S.E.	C.R.	P
DS → HOT	less than 5 years	.340	.240	.050	<.001
	more than 5 years	.060	.040	.050	.380

5 DISCUSSION

This study examined the interrelatedness of deep motivation, deep strategies, higher-order thinking, and digital literacy in higher education students. Structural equation modeling was utilized to analyze the proposed model, and the results indicated that the degree to which students exhibit deep motivation and employ deep strategies were both significant predictors of higher-order thinking and digital literacy. As such, all proposed paths in the model were found to be confirmed. These findings may have important implications for educational practice, as they suggest that fostering deep motivation and deep learning strategies may effectively promote digital literacy and higher-order thinking in higher education students.

The first conclusion is that deep learning should be promoted since it significantly fosters digital literacy. As Heinström [8] mentioned, deep motivation and deep strategies affect information-seeking outcomes and the ability to judge critical information. Moreover, online learners' motivation and use of appropriate learning strategies during the learning process can directly affect their success [15]. Therefore, by encouraging the development of deep motivation and deep strategies, educators may be able to support students' digital literacy development and enhance their overall success in the online learning environment.

Higher-order thinking also contributed significantly to digital literacy, which was the study's second conclusion. While this finding is consistent with much of the existing literature [1], [22], some differing viewpoints exist. For example, some scholars believe that digital literacy serves as the foundation for increasing higher-order thinking skills [28]. Nevertheless, we prefer the view that digital literacy and higher-order thinking are mutually reinforcing [22]. Even though many higher education students are already adept at using digital devices, it is still crucial to improve their digital literacy level, because digital literacy includes not only skills and cognition, but also social emotions [29], while higher-order thinking is just a manner of thinking [21]. Moreover, students' critical thinking and their ability to learn using higher-order thinking skills can both be enhanced through digital literacy. Likewise, developing students' higher-order thinking skills can also increase their digital literacy levels [22]. These findings highlight the importance of promoting higher-order thinking and digital literacy in educational contexts, as these competencies are mutually beneficial and can support students' success inside and outside the classroom.

In addition, consistent with existing literature [26], the study discovered an indication of a strong positive link between deep motivation, deep strategies, and higher-order thinking. However, several researchers have suggested that only deep strategies promoted higher-order thinking, and that deep motivation did not affect higher-order thinking [27], [49]. One possible explanation for this discrepancy is that deep motivation represents an internal psychological construct that is not easily observable and may be influenced by external factors. Additionally, it is possible that the participants' motivation gradually decreased over time.

Another interesting finding suggested that the impact of deep motivation on digital literacy was higher than that of deep strategies on digital literacy. Furthermore, the impact of deep motivation on higher-order thinking was also greater than that of deep strategies on higher-order thinking, suggesting that motivation plays a vital role in the learning process and can facilitate the development of more effective academic performance [33].

Lastly, through multi-group comparison analysis, the study also concluded that deep strategies had a positive impact on higher-order thinking among students with less than five years of digital experience, but had no effect on promoting higher-order thinking among students with more than five years of digital experience. This phenomenon may be due to the fact that when faced with the vast amount of information available in the digital world, learners tend to rely on customary and superficial learning strategies. This can be seen as a disadvantage of fragmented surface learning in an era of big Internet data [50]. Therefore, it is necessary not only to discuss the advantages of deep learning and higher-order thinking but also to consider the challenges that learners face in engaging in deep learning.

6 CONCLUSION

The present study aimed to investigate the factors influencing higher education students' digital literacy. The results showed that deep motivation, deep strategy, and higher-order thinking positively and significantly impact digital literacy. Based on these results, the study has important educational implications.

The first educational implication of this study is related to the importance of motivation in learning approaches. The study suggests that educators should set reflective questions in the teaching process to stimulate students' learning motivation. This is a specific factor that relates to a particular learning situation. By doing so, students can actively construct digital knowledge systems, raise questions, and enhance their problem-solving skills. As digital citizens with digital consciousness, learners need to be able to develop and apply deep strategies. Teachers can provide teaching intervention and a learning environment that fosters deep learning. For instance, situational, task-driven, and problem-based teaching methods can be used to implement learning activities. Independent inquiry learning, collaborative group learning, and problem-solving activities can also be introduced to help students use complex strategies to complete learning tasks and increase their digital literacy level.

Secondly, to enhance students' digital literacy, developing their higher-order thinking skills is important, which can help them effectively navigate the challenges of learning in a digital and information-rich environment. To achieve this, a systematic teaching approach is necessary to incorporate the development of high-level thinking into specific teaching designs. For instance, the five-step teaching method proposed by Limbach and Waugh [40] provides a useful framework for teachers to improve students' high-level thinking skills. This approach involves determining learning objectives, teaching through questioning, providing opportunities for practice before assessment, reviewing and refining learning, and providing feedback and assessment of learning. By actively engaging in this process, students can reflect on the meaning of what they are learning, and develop critical digital literacy competencies for exploring and classifying digital information.

The third important implication of this study is the need for educators to assess students' prior digital experiences and adapt their teaching strategies accordingly. As modern educational environments are not easily reformed, it is essential for educators to improve the digital literacy of a considerable number of students. In the classroom, teachers should employ pedagogical approaches that encourage students to reflect on their routine digital practices and engage in learning experiences that expand their external digital experiences. Additionally, policymakers should consider the importance of supporting and supplementing realistic situations that promote the development of digital literacy in educational settings.

The current study has several limitations. First, the participants were chosen randomly from two Chinese universities, making it impossible to extrapolate the findings to other situations. Secondly, while this study used quantitative research methods to analyze the data, measuring deep motivation using only a few items may not be easy. Thus, it is recommended that future studies use qualitative techniques, such as interviews or observations, to gain a deeper understanding of students' motivation. Lastly, this study only focused on the influence of the deep approach on digital literacy, while the other two learning approaches were not considered. Therefore, future research can involve more learning approaches and examine the critical factors of digital literacy to improve higher education students' digital literacy.

7 REFERENCES

[1] W. N. Yanuarto and A. Jaelani, "Higher thinking and digital literacy: Empowering technology for pre-service mathematics teacher," *Al-Jabar: Jurnal Pendidikan Matematika,* vol. 12, no. 2, pp. 329–342, 2021, https://doi.org/10.24042/ajpm.v12i2.9637

[2] R. Vuorikari Rina, S. Kluzer, and Y. Punie, "DigComp 2.2: The digital competence framework for citizens – With new examples of knowledge, skills and attitudes," RePEc – Econpapers, 2022, https://EconPapers.repec.org/RePEc:ipt:iptwpa:jrc128415 [Accessed: Jan. 18, 2023].

[3] International Telecommunication Union, "Measuring digital development: Facts and Figures 2022," ITU Hub, https://www.itu.int/hub/publication/d-ind-ict_mdd-2022/

[4] Y. Eshet, "Digital literacy: A conceptual framework for survival skills in the digital era," *Journal of Educational Multimedia and Hypermedia,* vol. 13, no. 1, pp. 93–106, Jan. 2004, [Online]. Available: https://www.learntechlib.org/primary/p/4793/

[5] P. Gilster, *Digital literacy.* New York; Chichester: Wiley Computer, 1997.

[6] A. Martin, "DigEuLit – A European framework for digital literacy: A progress report," *Journal of eLiteracy*, vol. 2, no. 2, pp. 130–136, 2005.

[7] N. B. Hamutoğlu, M. Savaşçi, and G. Sezen-Gültekin, "Digital literacy skills and attitudes towards e-learning," *Journal of Education and Future*, vol. 16, pp. 93–107, 2019, https://doi.org/10.30786/jef.509293

[8] J. Heinström, "Fast surfing, broad scanning and deep diving," *Journal of Documentation*, vol. 61, no. 2, pp. 228–247, 2005, https://doi.org/10.1108/00220410510585205

[9] D. D. Prior, J. Mazanov, D. Meacheam, G. Heaslip, and J. Hanson, "Attitude, digital literacy and self-efficacy: Flow-on effects for online learning behavior," *The Internet and Higher Education,* vol. 29, pp. 91–97, 2016, https://doi.org/10.1016/j.iheduc.2016.01.001

[10] S. Patmanthara and W. N. Hidayat, "Improving vocational high school students digital literacy skill through blended learning model," *Journal of Physics: Conference Series*, vol. 1028, p. 012076, 2018, https://doi.org/10.1088/1742-6596/1028/1/012076
[11] T. Shopova, "Digital literacy of students and its improvement at the university," *Journal on Efficiency and Responsibility in Education and Science*, vol. 7, no. 2, pp. 26–32, 2014, https://doi.org/10.7160/eriesj.2014.070201
[12] K. Krpálková Krelová, K. Berková, P. Krpálek, and A. Kubišová, "Attitudes of Czech college students toward digital literacy and their technical aids in times of COVID-19," *International Journal of Engineering Pedagogy,* vol. 11, no. 4, pp. 130–147, 2021, https://doi.org/10.3991/ijep.v11i4.20821
[13] P. Chatwattana, "Massive open online courses model with self-directed learning to enhance digital literacy skills," *International Journal of Engineering Pedagogy*, vol. 11, no. 5, pp. 122–137, 2021, https://doi.org/10.3991/ijep.v11i5.22461
[14] N. Aharony and H. Gur, "The relationships between personality, perceptual, cognitive and technological variables and students' level of information literacy," *Journal of Librarianship and Information Science*, vol. 51, no. 2, pp. 527–544, 2017, https://doi.org/10.1177/0961000617742450
[15] E. Kiliç-Çakmak, "Learning strategies and motivational factors predicting information literacy self-efficacy of e-learners," *Australasian Journal of Educational Technology*, vol. 26, no. 2, 2010, https://doi.org/10.14742/ajet.1090
[16] R. V. Small, N. Zakaria, and H. El-Figuigui, "Motivational aspects of information literacy skills instruction in community college libraries," *College & Research Libraries,* vol. 65, no. 2, pp. 96–121, 2004, https://doi.org/10.5860/crl.65.2.96
[17] G. J. Reece, "Critical thinking and cognitive transfer: Implications for the development of online information literacy tutorials," *Research Strategies*, vol. 20, no. 4, pp. 482–493, 2005, https://doi.org/10.1016/j.resstr.2006.12.018
[18] S. M. Zvacek, M. T. Restivo, and M. F. Chouzal, "Concept mapping for higher order thinking," *International Journal of Engineering Pedagogy,* vol. 3, no. S1, pp. 6–10, 2013, https://doi.org/10.3991/ijep.v3iS1.2401
[19] A. Lewis and D. Smith, "Defining higher order thinking," *Theory into Practice*, vol. 32, no. 3, pp. 131–137, 1993, https://doi.org/10.1080/00405849309543588
[20] Y. Yang and T. T. Zhao, "The construction of the blueprint of China college students higher-order thinking skills test," *Tsinghua Journal of Education*, vol. 39, no. 5, pp. 54–62, 2018, https://doi.org/10.14138/j.1001-4519.2018.05.005409
[21] National Education Association, *Preparing 21st-century students for a global society: An educator's guide to the "four Cs."* Washington, DC, 2012.
[22] M. Novitasari, S. Sutama, A. Narimo, and Fathoni, "Promoting literacy culture and character education to form high-level thinking students in elementary school," 2019. Accessed: Jan. 18, 2023. [Online]. Available: https://ijisrt.com/assets/upload/files/IJISRT19SEP1277.pdf
[23] T. F. Nelson Laird, R. Shoup, and G. D. Kuh, (2006, May). Measuring deep approaches to learning using the National Survey of Student Engagement. Paper presented at the annual meeting of the Association for Institutional Research, Chicago, IL, https://scholarworks.iu.edu/dspace/handle/2022/24141
[24] M. Pinho-Lopes and J. Macedo, "Project-based learning to promote high order thinking and problem-solving skills in Geotechnical courses," *International Journal of Engineering Pedagogy,* vol. 4, no. 5, pp. 20–27, 2014, https://doi.org/10.3991/ijep.v4i5.3535
[25] X. Tian and K. H. Park, "Learning approaches influence on college students' digital literacy: The role of self-determination theory," *International Journal of Emerging Technologies in Learning (Online)*, vol. 17, no. 14, pp. 78–93, 2022, https://doi.org/10.3991/ijet.v17i14.31413

[26] J. Lee and H. Choi, "What affects learner's higher-order thinking in technology-enhanced learning environments? The effects of learner factors," *Computers & Education,* vol. 115, pp. 143–152, 2017, https://doi.org/10.1016/j.compedu.2017.06.015
[27] J. Wang and X. Cui, "Research on the relationship model of deep learning motivation, strategy and higher-order thinking skills," *Journal of Distance Education,* vol. 6, pp. 41–52, 2017, https://doi.org/10.15881/j.cnki.cn33-1304/g4.2018.06.005
[28] I. W. Widana, I. W. Sumandya, K. Sukendra, and I. W. Sudiarsa, "Analysis of conceptual understanding, digital literacy, motivation, divergent of thinking, and creativity on the teachers skills in preparing hots-based assessments," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 12, no. 8, pp. 459–466, 2020, https://api.semanticscholar.org/CorpusID:225459643
[29] W. Ng, "Can we teach digital natives digital literacy?," *Computers & Education*, vol. 59, no. 3, pp. 1065–1078, 2012, https://doi.org/10.1016/j.compedu.2012.04.016
[30] Anusca Ferrari and Europeiska Kommissionen, *DIGCOMP: A framework for developing and understanding digital competence in Europe.* Luxembourg: Publications Office of the European Union, 2013.
[31] F. Marton and R. Säljö, "On qualitative differences in learning: I-Outcome and process," *British Journal of Educational Psychology*, vol. 46, no. 1, pp. 4–11, 1976, https://doi.org/10.1111/j.2044-8279.1976.tb02980.x
[32] J. B. Biggs, "Approaches to the enhancement of tertiary teaching," *Higher Education Research & Development,* vol. 8, no. 1, pp. 7–25, 1989, https://doi.org/10.1080/0729436890080102
[33] P. R. Pintrich and E. V. de Groot, "Motivational and self-regulated learning components of classroom academic performance," *Journal of Educational Psychology*, vol. 82, no. 1, pp. 33–40, 1990, https://doi.org/10.1037/0022-0663.82.1.33
[34] L. F. Zhang, "University students' learning approaches in three cultures: An investigation of Biggs's 3P model," *The Journal of Psychology,* vol. 134, no. 1, pp. 37–55, 2000, https://doi.org/10.1080/00223980009600847
[35] C. Janiesch, P. Zschech, and K. Heinrich, "Machine learning and deep learning," *Electronic Markets,* vol. 31, 2021, https://doi.org/10.1007/s12525-021-00475-2
[36] J. Maker, R. Zimmerman, A. K. Bahar, and C. In-Albon, "The influence of real engagement in active problem solving on deep learning: An important component of exceptional talent in the 21st Century context," *Australasian Journal of Gifted Education,* vol. 30, no. 2, 2021, https://doi.org/10.21505/ajge.2021.0014
[37] B. S. Bloom, *Taxonomy of educational objectives: The classification of educational goals.* Handbook 1, Cognitive Domain. New York: Longman, 1956.
[38] L. W. Anderson and D. R. Krathwohl, *A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy of educational objectives,* Essex: Pearson, 2001.
[39] Z. X. Zhong, "How to develop learners' higher-order thinking skills," *Journal of Distance Education,* vol. 4, no. 24, pp. 55–56, 2005, https://doi.org/10.15881/j.cnki.cn33-1304/g4.2005.04.024
[40] B. Limbach and W. Waugh, "Developing higher level thinking," *Journal of Instructional Pedagogies,* vol. 3, pp. 1–9, 2010.
[41] T. Garcia and P. R. Pintrich, "*Assessing students' motivation and learning strategies in the classroom context: The motivated strategies for learning questionnaire*," In *Alternatives in assessment of achievements, learning processes and prior knowledge,* Springer, Dordrecht, 1996, pp. 319–339, https://doi.org/10.1007/978-94-011-0657-3_12
[42] B. J. Zimmerman, "Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects," *American Educational Research Journal,* vol. 45, no. 1, pp. 166–183, 2008, https://doi.org/10.3102/0002831207312909

[43] M. Y. Pan and L. P. Dong, "Research on the classification, orientation and characteristic development of colleges and universities," *Educational Research*, no. 2, pp. 33–38, 2009.
[44] M. Prensky, "Digital natives, digital immigrants Part 1", *On the Horizon: The International Journal of Learning Futures*, vol. 9, no. 5, pp. 1–6, 2001, https://doi.org/10.1108/10748120110424816
[45] J. Biggs, D. Kember, and D. Y. P. Leung, "The revised two-factor study process questionnaire: R-SPQ-2F," *British Journal of Educational Psychology*, vol. 71, no. 1, pp. 133–149, 2001, https://doi.org/10.1348/000709901158433
[46] B. M. Byrne, *Structural equation modeling with AMOS: Basic concepts, applications, and programming*, Third Edition (3rd ed.). Routledge, 2016. https://doi.org/10.4324/9781315757421
[47] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservant variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39 –50, 1981, https://doi.org/10.1177/002224378101800104
[48] L. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives," *Structural Equation Modeling: A Multidisciplinary Journal*, vol. 6, no. 1, pp. 1–55, 1999, https://doi.org/10.1080/10705519909540118
[49] J. C. Liang, Y.-Y. Chen, H. Y. Hsu, T. S. Chu, and C. C. Tsai, "The relationships between the medical learners' motivations and strategies to learning medicine and learning outcomes," *Medical Education Online*, vol. 23, no. 1, p. 1497373, 2018, https://doi.org/10.1080/10872981.2018.1497373
[50] Y. Xie, "Analysis of advantages and disadvantages of fragmented learning in the era of Internet big data," 2021 2nd International Conference on Information Science and Education (ICISE-IE), Nov. 2021, https://doi.org/10.1109/ICISE-IE53922.2021.00204

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PAPER

Survey Analysis on Engineering Students' Experience of Future-fit Classroom Learning Environment

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ABSTRACT

The success of every educational activity hinges on the quality of the students' learning experiences. This survey-based study analysed engineering students' perceptions of their learning experiences in a future-fit classroom (FFC) compared with conventional classrooms. In this study, structured interviews using online questionnaire, that were filled out by the students, was employed as a tool. Descriptive statistics for mean, coefficient of variation (CV), as well as linear correlation coefficient, were performed to evaluate the connection between their responses using the KNIME analytical software. According to the study, the typical response rate at which individuals responded to agree to questions regarding their educational experience in the FFC classroom is approximately 82 mean percentage score (MPS) with a CV of 0.196. Also, the mean response rate from the students who agreed that the University management should invest in FFCs is 86 MPS and 0.288 CV. Key insights from the further analysis include the correlation of students' responses to interpret the determining factors for their responses. These results indicate that most of the students that participated in the study are prepared to have more experiences in the FFCs for improved technology-enhanced learning and new pedagogy. Education policymakers should consider the use of communication and information technology in university classrooms to enhance students' engagement and improve pedagogy, which can lead to improved academic performance.

KEYWORDS

innovative learning environment, future-fit classroom, engineering students' perception, communication technology, pedagogy

1 INTRODUCTION

Future-fit classroom (FFC) learning environments are being built all over the world because of the growing impact of technology in higher education and the societal trend towards embracing intelligent systems [1]. Students today want more from their universities and are more open to trying new teaching techniques, including smart classroom equipment [2]. Trends in academia are following the same pattern.

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The use of technology in education has always impacted both the content and delivery of lessons, but recently technologies like artificial intelligence are reshaping how we learn and discover new things. Therefore, technology in schools is evolving from its traditional role as primarily a pedagogical instrument and a method of gaining access to information for the achievement of big ideas [3], [4].

The term "future-fit classroom" refers to an innovative approach to teaching and learning using technological tools that help students grow in their thinking, knowledge, and literacy. In other words, an FFC is a traditional classroom that has been upgraded to include advanced instructional technologies and educational resources. In this setting, students can engage in formal education in ways that go beyond what is achievable in conventional classrooms [5].

The contributions of this work include the validated results that showed that an FFC offered a better teaching and learning experience for instructors and learners as experimented with a class of engineering students who are enrolled in academic programs at the University of Johannesburg, located in South Africa. The coefficient of variation method and mean method were used for calculation and the correlation of the responses was used to find the determining factors of the student's responses.

The remaining sections of the paper are organised as described below: Section 2 provides a literature review, Section 3 outlines the methodology, Section 4 presents the results, and Section 5 contains the discussions and conclusions.

2 LITERATURE REVIEW

The FFC has been shown to increase students' enthusiasm to study, foster an atmosphere of active learning, and boost overall academic achievement as argued by [6]–[9]. Furthermore, various studies, including [10], have observed that the educational setting has an impact on how people behave, and this impact can lead to both immediate and long-term effects on academic performance and instructional effectiveness. Therefore, researchers study how to implement FFCs since doing so will inherently encourage students to be more active scholars. In the literature, "future-fit classrooms" are used frequently as "smart classrooms" or "blended learning" [11], [12]. Although an FFC can improve student learning, the extent of this effect is less certain.

Analysis of data from global research done to verify the dynamic model of educational efficacy by [13] showed that students' evaluations are a viable and reliable way to evaluate the model's components using learning analytics. Learning analytics involves the collection, analysis, and appropriate distribution of relevant data generated by students, which can be used to provide appropriate cognitive, administrative, and other forms of support to enhance the learning experience [13]. KNIME, which stands for Konstanz Information Miner, is open-source software and it is utilised to analyse data [14]. The software can generate visual depictions of diverse types of data, making it comprehensible for other users as well. KNIME has demonstrated its adaptability and usefulness across various fields of knowledge [15].

In this study, we use a case study approach with objective sampling. The study's findings will be relevant to the emerging topic of "future-fit classrooms" or "future learning environments". The perceived contradiction between innovation theories and practices in higher education and ICT sectors prompted the study. To that aim, this research explores how students perceive their ideal learning settings in the future, with a focus on how they aspire to the technology being integrated and their desired learning experience.

3 METHODOLOGY OF THE RESEARCH

In this section, we present the primary objectives and inquiries of the research, along with the classroom feedback mechanism, information origins, individuals, research method, and analytical approach.

The layout of the FFC at the University of Johannesburg where the lecture sessions were held is depicted in Figure 1. This comprises a range of equipment such as a touchscreen display, digital content projectors, collaborative tools between students and teachers, automated evaluation and response systems, cameras for capturing and archiving lectures, and a smart physical environment that uses sensors to control the temperature, humidity, air quality, and sound in the room.

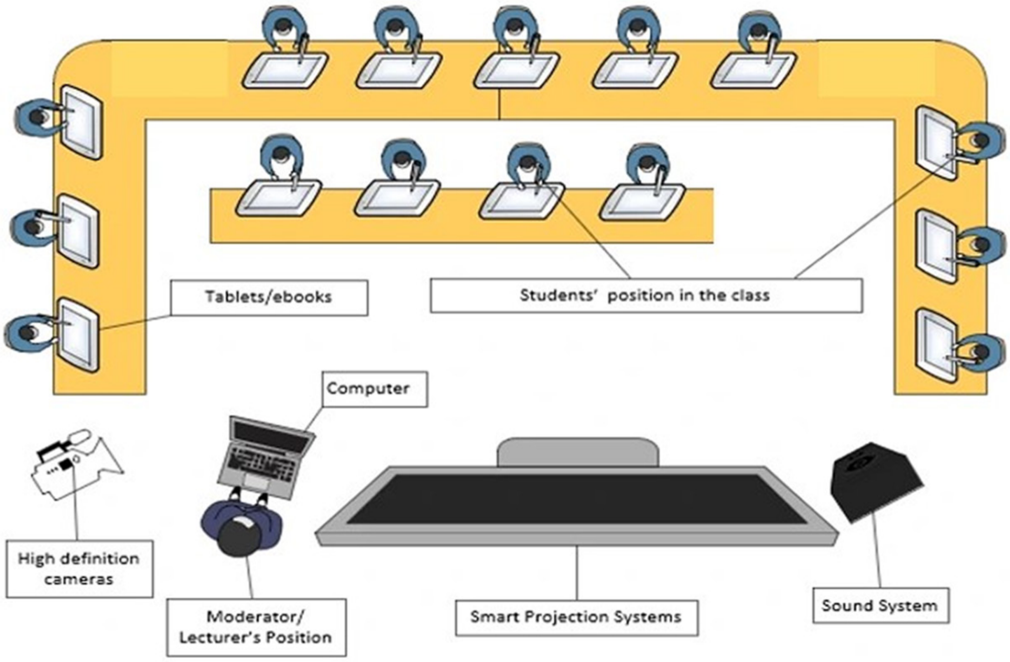

Fig. 1. Layout of the experimental future-fit classroom at the University of Johannesburg

3.1 The research goal and questions

The descriptive qualitative and quantitative methodology was used for this study's research design to present a comprehensive description of the research study. This research strategy fits most well with explanatory and exploratory critical theories like constructivist learning theory [16]. The aim of this study, which uses both qualitative and quantitative descriptive methods, is to provide a detailed summary of the response of the students to an FFC. The individuals involved in the research were first-year students enrolled in the Department of Electrical and Electronic Engineering Science at the University of Johannesburg (UJ) during the academic year of 2022. They participated in the future-fit classroom learning in the module called Project Communication 1B (PJCEEB1). Engineering students form a good sample space for such a study as these as they have been constructively used in previous pedagogy studies such as the studies presented in [17] for technical engineering students, and [18]–[20] for degree engineering students.

The subsequent research inquiries were established to provide answers to the following research questions:

- What inspired the students to willingly participate in the future-fit classroom?
- What did the students appreciate about the future-fit classroom?
- Are there any recommendations or remarks from the students that could enhance the FFC for future use and deployment in the university and country at large?
- Is there a noticeable contrast in the students' learning experience between the conventional classroom and the FFC?

3.2 Data collection and sampling

The classes were held in hybrid mode; hence some students attended the class in-person at the FFC while others attended virtually on Blackboard Collaborate Ultra, which is the official Learning Management System used at UJ for teaching, learning, and examination [21]. The total sample population who attended the FFC hybrid classes was 60 registered students of the module. Fifteen students attended the in-person class since that is the maximum capacity of the FFC, while forty-five students joined the class online through the Blackboard learning management system of UJ.

According to Alamri's demonstration in [22], Slovin's formula in equation (1) was utilised to determine the smallest amount of representative sample size required in the research:

$$\eta = \frac{N}{1+(N \times e^2)} \tag{1}$$

The formula provided includes three variables: 'η' which represents the sample size, '*N*' which represents the population, and 'e' which represents the acceptable level of sampling error that is 10%. According to (1), the minimum number of participants required for the in-person attendance group in this study is 13, while the minimum number of participants needed for the virtual attendance group is 31. The survey received responses from 14 in-person and 36 online students, totaling 50 students that participated in the survey (83% of total responses received).

The instrument employed in the form of a questionnaire was created using Google Forms so that students could readily reply to the teaching methods conducted by the course instructor during the FFC lecture sessions. The researchers used both the previous literature and the questions generated by the project studies to obtain the questions they wanted to be answered in their assessment of students' experience at the FFCs. In addition to standard demographic questions, the questionnaire explored respondents' perceptions toward and interest in the FFC's pedagogical methods. It also consisted of multiple-choice questions scored on a scale of five ("strongly agree" (5), "somewhat agree" (4), "neutral" (3), "somewhat disagree" (2), and "strongly disagree" (1)). The participants were also asked some open-ended questions.

Validity and reliability limitations were circumvented by asking specific and unambiguous questions. Expert academics and lecturers in the field of engineering education and technology reviewed the questionnaire for content validity [23]. The research questions were evaluated based on reflectiveness to assess understanding, discrimination, or evaluation. This was to ensure that the questionnaires were clear and did not include any terminology that would make the participants lose interest in the survey.

3.3 Ethical considerations

The research was conducted following national and international research ethical requirements such as autonomy, beneficence, non-maleficence, and justice, including those presented in [24]. This study was conducted with informed and voluntary consent from all the students involved. Prospective participants were also informed of the significance of their involvement and what would be done with the information they submitted. Approval from the faculty's ethics committee was obtained before the research commenced.

3.4 Data and visualization

Analysis of the qualitative data was based on content analysis. Content analysis is a known data analysis strategy that has progressed in interpreting textual data [25]. Students' perspectives, acceptance, and the necessity for FFC were the three major themes identified by the analysis of all the responses. The students' feedback was exported into a spreadsheet (MS Excel) from Google spreadsheet and saved using the comma-separated-value (CSV) format for further analysis. The responses to the Likert-scale questions were then converted from strings to numbers and the quantitative data obtained from the study were analysed and presented using the KNIME analytical software.

The numeric variables were analysed using descriptive statistics, specifically the mean and standard deviation. Since the scoring system varies between 1 and 5, it is important to recognize that each question's number corresponds to a distinct level of agreement. A low mean value for a question interprets that the students disagree, whereas a higher mean value interprets that the students agree. The CV method as used in [26] is used to weigh the responses to the questionnaires. The CV represents the relationship between the standard deviation and the mean, expressed as illustrated in equation (2):

$$CV = SD/m \tag{2}$$

In equation (2), *CV* represents "coefficient of variation", *SD* represents "standard deviation", and *m* represents "mean". It calculates the variation degree of the responses index in the data by directly using the information contained in each index, and it is an objective weighting method. If the responses from sample A and sample B vary less, it implies that the data points are dispersed around the mean value, which provides a simple data interpretation. The data that has a CV score that exceeds 1 is regarded to require further analysis in order to draw a conclusion.

The data preprocessing procedures executed on the KNIME workflows include reading the input file, column filtering, and checking for missing data. An information examination process comprises a pipeline of a node associated with edges that transport either information or models. The workflows were executed, and students' response data visualization results were obtained. The designed KNIME workflow is presented in Figure 2.

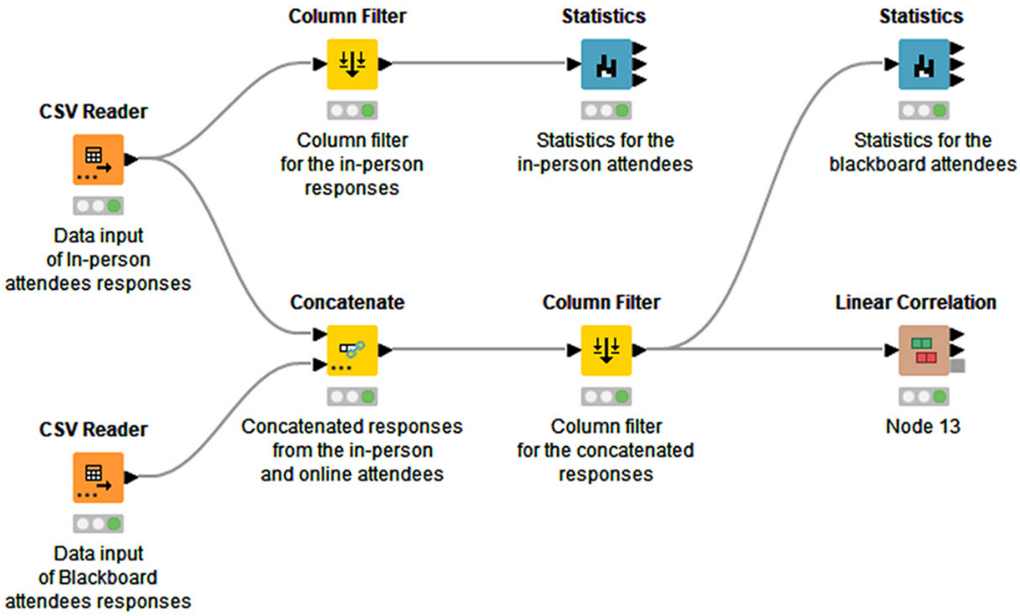

Fig. 2. KNIME software workflow with built-up nodes

4 RESULTS AND DISCUSSION

An evaluation of the student's learning experience and level of satisfaction with the FFC lecture section is presented in this section. The survey measures students' concentration, engagement, perceived learning, motivation, and satisfaction. This survey received 50 responses from the students – 14 responses from in-person attendees and 36 responses from virtual attendees.

4.1 Analysis of Students' satisfaction levels

After collecting the responses in numerical format, we proceed to determine the mean value of the answers for each question. We employed the KNIME mathematical formula node to compute both the mean values and the correlation coefficient. This section presents the statistics data for the responses from the two groups of students that participated in the FFC session. The attendees who were physically present provided answers to questions regarding the facilities that aid in learning activities within the FFC. Both the in-person and virtual attendees' feedback assessed the extent to which the FFC facilitated learning activities. The maximum and minimum scores are 5 and 1, respectively. Low scores mean that the students did not agree with the question while a high score means that the students agreed with the question as explained in Section 3.2 of this paper.

Response to questions in Table 1 was targeted to the in-person attendees and was analysed based on responses from the in-person attendees only. It presents the quantitative analysis of responses of students to analyse the FFC physical environment and classroom facilities.

Table 1. Quantitative analysis of in-person attendees' responses

Questionnaires	Min	Max	Mean	MPS (%)	Std. Deviation	CV
"The future-fit class allowed the lecturer to ask each of us if we understood what she was teaching and to assist us if we had any questions."	3	5	4.22	85	0.764	0.181
"The future-fit class provided an adequate balance of theoretical and practical knowledge."	3	5	4.143	83	0.535	0.13
"The future-fit classroom amenities (ventilation and air quality, space and size of the classrooms, soundproof wall, lighting, internet connection, teaching facilities, and temperature control) met your needs."	3	5	4.572	92	0.852	0.187
"The future-fit classroom's teaching environment aided better learning and understanding of the course content."	3	5	4.286	86	0.612	0.143
"The room temperature of the future-fit classroom is conducive for learning."	4	5	4.786	96	0.426	0.089
"There are no unnecessary sounds in the future-fit classroom."	4	5	4.858	98	0.364	0.075
"The lighting in the future-fit classroom is adequate for teaching and learning."	3	5	4.858	98	0.535	0.111
"I can hear the lecturer and other students (online and in-person)."	4	5	4.14	83	1.196	0.289
"I can effectively collaborate with a classmate on class tasks during a hybrid future-fit class."	3	5	4.04	81	1.106	0.274
"In-person future-fit classes allow for real-time formative assessment by the lecturer."	3	5	4.643	93	0.745	0.161
"I have enough space in the future-fit class to place my textbooks, tablets, PCs, and other materials."	3	5	4.5	90	0.651	0.145
"The classroom layout is appropriate for my learning styles."	3	5	4.643	93	0.634	0.137
"The blackboard and projector are in the ideal location for teaching and learning in the future-fit class."	3	5	4.358	88	0.842	0.194
"I understand educational content easier and faster when it is taught from a smart screen than just on a projector screen."	3	5	4.143	83	0.865	0.209
"I can share my learning experiences easily with others."	4	5	4.14	83	0.809	0.196
"The future-fit classroom is roomy enough for all class activities."	2	5	4.072	81	0.998	0.245

The finding in Table 1 was useful in evaluating the perception of students' satisfaction level in the physical FFC session. The analysis of responses on the facilities provided in the physical FFC session is highly positive with an overall average MPS of 88%. However, there is still a need for improvement as not all the students are fully satisfied with the facilities provided by the FFC. Table 2 presents the quantitative analysis of the total responses received in the survey from both in-person and online participants of the FFC.

Table 2. Quantitative analysis of all FFC hybrid class attendees' responses

Questionnaires	Min	Max	Mean	MSP (%)	Std. Deviation	CV
"All lecture halls at UJ should have smart screens and boards, similar to the future-fit classrooms"	1	5	4.277	86	1.16	0.288
"Do you believe investing in the future-fit classroom by the University management was worthwhile?"	1	5	4.000	80	0.794	0.196
"Do you believe the University offers you appropriate facilities for optimal learning in a regular classroom setting?"	1	3	3.532	71	0.764	0.22
"How likely are you to recommend the future-fit classroom session to your friends or colleagues based on your overall experience in it?"	1	3	4.360	87	1.174	0.27
"How would you rate your entire academic experience with the lecturer in the future-fit class?"	2	5	4.086	82	0.829	0.195
"I can hear the lecturer and other students (virtual and in-person)"	1	5	4.107	83	0.612	0.143
"I can share my learning experiences easily with others"	2	5	4.107	83	1.018	0.245
"Introducing future-fit classrooms for all modules will effectively improve my academic performance"	1	5	4.128	83	1.085	0.277
"Introducing the future-fit classroom will effectively prepare me for the job market"	1	5	3.894	78	1.143	0.286
"The future-fit class allowed the lecturer to ask each of us if we understood what she was teaching and to assist us if we had any questions"	2	5	3.915	79	1.196	0.289
"The future-fit class provided an adequate balance of theoretical and practical knowledge"	2	5	3.490	70	0.809	0.196

As seen in Table 2, based on the response to the question, "Do you believe the University offers you appropriate facilities for optimal learning in a regular classroom setting?" the students agree that the university offers the appropriate facilities considering the response with 71% MPS value and 0.22 CV. This low MPS could be because there were more online than in-person participants in the survey who didn't have direct interaction with the FFC. However, in the case of recommending the FFC based on their experience, their responses had an MPS value of 87% and a CV of 0.27, which can be motivation for the authorities to deploy more FFC across the campus. Considering the FFC's rating on assisting the student's academic experience, it was observed that the MPS to the question is 82%, and the CV is 0.196. This might also be the justification for the result of the question "Introducing future-fit classrooms for all modules will effectively improve my academic performance," where the MPS is 83% and the CV is 0.277. Furthermore, to evaluate the level of student satisfaction based on the response to the question, "All lecture halls at UJ should have smart screens and boards, similar to the future-fit classrooms," we observed the students' responses have an MPS of 86% and 0.288 CV. Hence, these are positive indications that the FFC would offer more benefits to the students than the traditional classrooms even as the university management addresses the shortcomings of the FFC.

4.2 Correlation of students' response to the FFC

The purpose of this section is to explore the correlation between answers to questions treated as factors and determine how strong or weak they are. Also, this gives us an idea of how a response to one factor affects others. This will be achieved by applying a linear correlation between these results, and based on the results, we will be able to determine the correlation between them. According to our research results, we will classify values ranging from 0 to 0.29 as indicating weak positive relationships, values ranging from 0.3 to 0.69 as indicating moderate positive relationships, and values ranging from 0.7 to 0.99 as indicating strong positive relationships. Firstly, it is important to comprehend that the correlation coefficient falls within the range of –1 to +1. A value of +1 signifies an ideal positive correlation. A score of 0 indicates the absence of any correlation, whereas a score of –1 signifies a completely inverse correlation.

The correlation value between "Were you part of the hybrid future-fit class teaching and learning?" and "How would you rate your entire academic experience with the lecturer in the future-fit class?" is 0.24. The weak correlation between students' rating of the FFC and the mode of participation can be explained by the environmental variables namely the location, noise level, distractions, reliable internet and/or computer, and inadequate interpersonal interactions as reported in their responses.

4.3 Analysis of open-ended responses

The qualitative data received from the survey was analysed and categorised into four primary themes, namely inspiration, appreciation, displeasure, and feedback/suggestions for the FFC on UJ campus. The results are summarised and presented in Table 3.

Table 3. Analysis of motivations to participate in the FFC

Primary theme	Question	Secondary Theme	Selected Students' Responses
Inspiration	"What inspired you to willingly participate in the future-fit class?"	The use of innovative technological gadgets	"I was interested in technological innovations"
			"I want to experience the futuristic nature of learning"
		Experience of a new classroom setting	"To see how the integrated classroom operates"
Appreciation	"What do you appreciate best about the future-fit classroom and explain why."	Study materials handling	"I have more space to put your study materials"
		Class Interaction and students engagement	"I was able to ask questions"
			"I appreciate the interactive communication between virtual and in-person students"
Displeasure	"Mention one thing you disliked most about the future-fit classroom and explain why?"	Interruption of the network connection	"The technical difficulty caused the waste of some lesson time"
		The small size of the class	"There should be more space to accommodate more students in the in-person participation of the FFC session"
		Cost	"It looks expensive."
Feedback comments and suggestions	"Do you have any suggestions or comments to help improve the future-fit classroom experience for students?"	Improvement in smart devices and furniture	"Practical equipment can be installed to aid the learning of practical subjects."
			"The capacity of the future-fit classroom needs to be increased to accommodate more students"

4.4 Discussion

The results of this study address the research objective to analyse engineering students' perceptions of their learning experiences in a technologically enhanced classroom (FFC) compared to conventional classrooms. The quantitative data was evaluated thoroughly using the MPS, CV and linear correlation methods to identify indicators for the different responses.

The findings of this study are consistent with earlier research that examined how students perceived similar technologies like the FFC for different applications such as intellectual disabilities [27], STEM subjects [28], flipped classrooms [29], smart classrooms [30], subject websites [31], and remote learning [32]. Student satisfaction was found to be predictably associated with classroom facilities. The results of this study are crucial because nearly all the participants were enthusiastic about trying the FFC session at the university for the very first time. Moreover, the introduction of the FFC was a novel occurrence at the university. Consequently, we obtained a restricted number of devices and amenities that students could utilise during the session. Although many factors influence students' satisfaction levels, our research indicates that the absence of a face-to-face classroom environment is a significant contributor to negative perceptions among students who joined virtually as previously opined by the work in [33].

The literature shows that previous assessments have analysed students' perceptions from different academic levels, but this research focused mainly on the perspectives of engineering students in higher institutions towards the FFC. According to the findings of the qualitative analysis of the survey, students' perspectives and expectations regarding the FFC are labelled under four primary themes, namely inspiration, appreciation, displeasure, and feedback comments/suggestions. Most of the respondents concurred that the classroom amenities were beneficial, and efficient, and facilitated their learning process without many drawbacks except for issues of network connectivity, class sitting capacity, cost, and inability to conduct laboratory practicals there.

5 CONCLUSION

A study of students' experience and responses to the FFC learning environment at the University of Johannesburg has been presented in this article. The questions and answers were submitted and received electronically through Google Forms. The surveys asked participants to evaluate their levels of motivation, engagement, enjoyment, perceived learning, and overall satisfaction with the classroom's preparation for the future of learning at the university. These findings provide more evidence that students opined that the digital equipment used in a future-fit classroom aids their education and boosts their focus, interest, enthusiasm, and drive to study. It also increased their learning capability by making students more self-aware of their progress in the subject being taught in the class. In addition, the scholars perceive that their feedback and viewpoints are esteemed by their instructors and will be utilised by the university administration to enhance the quality of education.
Furthermore, the traditional classroom was shaped by the industrial age and the future-fit classroom will be shaped by the digital revolution.

This study has limitations due to the limited sample size, small sitting capacity of the FFC, and a focus on convenience sampling. Hence, further research should focus on testing different student groups' classroom experiences and examining the learning outcomes of large samples in a larger FCC. Considering the study's discoveries, forthcoming investigations could investigate how technology affects student learning achievements across diverse academic fields and educational stages.

However, this study has shown that the deployment of more and larger FFCs is the right way to go at the University of Johannesburg, which other institutions can also invest in for the good of their students.

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7 REFERENCES

[1] M. D. González-Zamar, E. Abad-Segura, E. López-Meneses, and J. Gómez-Galán, "Managing ICT for sustainable education: Research analysis in the context of higher education," *Sustainability*, vol. 12, no. 19, p. 8254, 2020, https://doi.org/10.3390/su12198254

[2] J. Faritha Banu, R. Revathi, M. Suganya, and N. R. Gladiss Merlin, "IoT-based cloud integrated smart classroom for smart and a sustainable campus," *Procedia Comput Sci*, vol. 172, pp. 77–81, 2020, https://doi.org/10.1016/j.procs.2020.05.012

[3] M. Kwet and P. Prinsloo, "The 'smart' classroom: A new frontier in the age of the smart university," *Teaching in Higher Education*, vol. 25, no. 4, pp. 510–526, 2020, https://doi.org/10.1080/13562517.2020.1734922

[4] A. T. Pham, "Engineering students' perception of using webcams in virtual English classes," *International Journal of Engineering Pedagogy*, vol. 12, no. 6, pp. 115–127, 2022, https://doi.org/10.3991/ijep.v12i6.33317

[5] G. Cebrián, R. Palau, and J. Mogas, "The smart classroom as a means to the development of ESD methodologies," *Sustainability (Switzerland)*, vol. 12, no. 7, 2020, https://doi.org/10.3390/su12073010

[6] S. K. S. Cheung, L. F. Kwok, K. Phusavat, and H. H. Yang, "Shaping the future learning environments with smart elements: Challenges and opportunities," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, pp. 1–9, 2021, https://doi.org/10.1186/s41239-021-00254-1

[7] K. Lu, H. H. Yang, Y. Shi, and X. Wang, "Examining the key influencing factors on college students' higher-order thinking skills in the smart classroom environment," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, pp. 1–13, 2021, https://doi.org/10.1186/s41239-020-00238-7

[8] W. Di, X. Danxia, and L. Chun, "The effects of learner factors on higher-order thinking in the smart classroom environment," *Journal of Computers in Education*, vol. 6, no. 4, pp. 483–498, 2019, https://doi.org/10.1007/s40692-019-00146-4

[9] C. Guo and Y. Huang, "Effect of mobile devices and software in collaborative learning smart classroom on students' learning motivation," *ACM International Conference Proceeding Series*, pp. 24–28, 2021, https://doi.org/10.1145/3474995.3475000

[10] G. Ö. İra, "Classroom teachers' views on the physical learning environments of primary schools in Turkey," 2021.

[11] H. Uzunboylu and D. Karagozlu, "Flipped classroom: A review of recent literature," *World Journal on Educational Technology: Current Issues*, vol. 7, no. 2, pp. 142–147, 2015, https://doi.org/10.18844/wjet.v7i2.46

[12] M. K. Saini and N. Goel, "How smart are smart classrooms? A review of smart classroom technologies," *ACM Comput Surv*, vol. 52, no. 6, 2019, https://doi.org/10.1145/3365757

[13] L. Kyriakides *et al.*, "Using student ratings to measure quality of teaching in six European countries," vol. 37, no. 2, pp. 125–143, 2014, https://doi.org/10.1080/02619768.2014.882311

[14] KNIME AG, "KNIME Workflow Invocation Guide," version 4.7, 2022. Available at: https://docs.knime.com/latest/analytics_platform_workflow_invocation_guide/analytics_platform_workflow_invocation_guide.pdf. Accessed 11 April 2023.

[15] R. A. Dorr, J. J. Casal, and R. Toriano, "Text mining of biomedical articles using the konstanz information miner (KNIME) platform: Hemolytic uremic syndrome as a case study," *Health Inform Res*, vol. 28, no. 3, pp. 276–283, 2022, https://doi.org/10.4258/hir.2022.28.3.276

[16] L. Doyle, C. McCabe, B. Keogh, A. Brady, and M. McCann, "An overview of the qualitative descriptive design within nursing research," vol. 25, no. 5, pp. 443–455, 2019, https://doi.org/10.1177/1744987119880234

[17] O. M. Longe, O. B. Imoukhuede, A. A. Obolo, and K. Ouahada, "A survey on the experiences of women in engineering: An institutional study," *IEEE AFRICON Conference*, vol. 2019, 2019, https://doi.org/10.1109/AFRICON46755.2019.9133875

[18] N. Nwulu, U. Damisa, and S. L. Gbadamosi, "Students perception about the use of Jupyter notebook in power systems education," *International Journal of Engineering Pedagogy*, vol. 11, no. 1, pp. 78–86, 2021, https://doi.org/10.3991/ijep.v11i1.14769

[19] N. Van Hanh and N. T. Long, "The ethical perception of engineering students who have never participated in the ethics curriculum," *International Journal of Engineering Pedagogy*, vol. 12, no. 1, pp. 4–20, 2022, https://doi.org/10.3991/ijep.v12i1.21781

[20] N. H. K. Anuar, N. Othman, N. Kasuan, N. A. Muhamad, M. Abdul Majid, and E. H. Mat Saat, "An evaluation of the student entrance-exit survey (EES) and PO score for the electric circuit II course," *International Journal of Academic Research in Progressive Education and Development*, vol. 12, no. 1, pp. 251–260, 2023, https://doi.org/10.6007/IJARPED/v12-i1/16131

[21] N. N. M. Kasim and F. Khalid, "Choosing the right learning management system (LMS) for the higher education institution context: A systematic review," *International Journal of Emerging Technologies in Learning*, vol. 11, no. 6, pp. 55–61, 2016, https://doi.org/10.3991/ijet.v11i06.5644

[22] A. F. Alamri *et al.*, "Perception of healthcare providers during the Covid-19 pandemic: A mixed method survey in an integrated healthcare delivery system in Saudi Arabia," *Int J Environ Res Public Health*, vol. 19, no. 24, 2022, https://doi.org/10.3390/ijerph192416676

[23] H. Herdoost, "Validity and reliability of the research instrument; how to test the validation of a questionnaire/survey in a research hamed taherdoost to cite this version: HAL Id: hal-02546799 validity and reliability of the research instrument; how to test the," *International Journal of Academic Research in Management*, vol. 5, no. 3, pp. 28–36, 2016. https://doi.org/10.2139/ssrn.3205040

[24] E. Gefenas, J. Lekstutiene, V. Lukaseviciene, M. Hartlev, M. Mourby, and K. Cathaoir, "Controversies between regulations of research ethics and protection of personal data: Informed consent at a cross-road," *Med Health Care Philos*, vol. 25, no. 1, pp. 23–30, 2022, https://doi.org/10.1007/s11019-021-10060-1

[25] A. J. Kleinheksel, N. Rockich-Winston, H. Tawfik, and T. R. Wyatt, "Demystifying content analysis," *Am J Pharm Educ*, vol. 84, no. 1, pp. 127–137, 2020, https://doi.org/10.5688/ajpe7113

[26] T. Chen, L. Peng, B. Jing, C. Wu, J. Yang, and G. Cong, "The impact of the COVID-19 pandemic on user experience with online education platforms in China," *Sustainability (Switzerland)*, vol. 12, no. 18, pp. 1–31, 2020, https://doi.org/10.3390/su12187329

[27] A. L. Vasquez Ubaldo, V. Y. Gutierrez-Barreto, F. Sierra-Liñan, and M. Cabanillas-Carbonell, "Application of learning software in basic education students with intellectual disabilities: A systematic review of the literature," *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 1, pp. 45–64, 2023, https://doi.org/10.3991/ijep.v13i1.35677

[28] O. Kuzmenko, S. Dembitska, M. Miastkovska, I. Savchenko, and V. Demianenko, "Onto-oriented information systems for teaching physics and technical disciplines by STEM-environment," *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 2, pp. 139–146, 2023, https://doi.org/10.3991/ijep.v13i2.36245

[29] G. Akçayır and M. Akçayır, "The flipped classroom: A review of its advantages and challenges," *Comput Educ*, vol. 126, pp. 334–345, 2018, https://doi.org/10.1016/j.compedu.2018.07.021

[30] Y. Zhang, X. Li, L. Zhu, X. Dong, and Q. Hao, "What is a smart classroom? A literature review," pp. 25–40, 2019, https://doi.org/10.1007/978-981-13-9439-3_2

[31] H. M. Selim, "An empirical investigation of student acceptance of course websites," *Comput Educ*, vol. 40, no. 4, pp. 343–360, 2003, https://doi.org/10.1016/S0360-1315(02)00142-2

[32] I. F. Adi Badiozaman, H. J. Leong, and W. Wong, "Embracing educational disruption: A case study in making the shift to a remote learning environment," *Journal of Applied Research in Higher Education*, vol. 14, no. 1, pp. 1–15, 2022, https://doi.org/10.1108/JARHE-08-2020-0256

[33] J. Corzo-Zavaleta, R. Yon-Alva, J. Icho-Yacupoma, Y. Principe Somoza, L. Andrade-Arenas, and N. I. Vargas-Cuentas, "Hybrid learning in times of pandemic Covid-19: An experience in a Lima university," *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 1, pp. 65–81, 2023, https://doi.org/10.3991/ijep.v13i1.36393

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PAPER

The Effectiveness of the Application of Game-Based E-Learning on Academic Achievement in Mathematics for Students in Jordan

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ABSTRACT

Mathematics is an abstract and complex subject for children that needs new ways of teaching. Therefore, this study explores the effectiveness of a computer game application called "My Math Academy" for learning mathematics on the academic achievement of early learning students in Jordan. My Math Academy computer game app is educational content through games that are adaptable to the curricula. The study sample consisted of ten students from kindergarten, first and second grades from eight schools in the city of Amman during the academic year 2022/2023 during the first and second semesters. They were divided into two groups: the treatment group, which consisted of 505 students, and a control group consisting of 481 students. The students of the treatment group were gradually trained to use the My Math Academy application, and the results showed through the data obtained that the treatment group that was taught with the support of My Math Academy obtained higher academic scores in mathematics compared to the control group that was taught in the traditional way. It was observed that the effect of the application of computer games to the academic achievement of students with severe arithmetic weaknesses is much greater than the effect of other students who excelled in mathematics.

KEYWORDS

game-based e-learning, mathematics, the academic achievement

1 INTRODUCTION

All over the globe, the form of education is changing from traditional methods to modern technology to comply with the rapid technological revolution [1]. Nowadays, technological games are used through mobile phones, digital assistants, tablets, and computers to support all those working in the field of education [2]. The use of learning based on adaptive electronic games through mobile phones in the education process is fun for children [3]. It enhances motivation to learn among students and is effective in

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the field of problem solving in mathematics [4]. Mobile learning can be defined as the process of acquiring information and skills through electronic applications [5]. There is no doubt that education through play in the early stages of special education for young children facilitates knowledge because it considers the age stage and corresponds with it [6]. The main objective of this paper is to investigate the impact of a game-based e-learning application on academic achievement in mathematics for students in Jordan.

2 RELATED WORK

2.1 Game-based e-learning

Mobile gaming technologies have transformed the teaching process in and out of the classroom [7]. It is noticeable in this era that the use of mobile phones is widespread, and mobile phones contain a variety of settings, giving students a wide range of modern and advanced uses of gaming technology in learning [8]. Learning through games is represented by individuality, and it is personal learning that is characterized by a response to the personal requirements of the student and is also characterized by the possibility of mobility and communication through global electronic platforms and networks [9]. Learning through games shapes students' knowledge and skills [10]. A great deal of research has led to the fact that learning through games has a real and positive effect on students' learning and development, especially in some subjects such as Arabic, mathematics and science [11–12]. That children learn well when the question in mathematics is in the form of a puzzle in a game and they are mentally active through games, especially questions in mathematics that need counting and thinking [13–16]. Learning through games builds social ties between learners and creates links for communication and learning between them with ease [17–20]. In addition, learning through games stimulates children's minds and increases their acceptance of learning [21–23]. Play is not only a great source of fun, but it can also be a source for children to learn and develop, because learning through games encourages students to show their intellectual abilities through play [25]. When the student plays, he experiences new knowledge [28]. Play is the field in which the child learns. The teacher can conduct experiments, by giving each child a role in the story while playing [26]. At the end of the story, all the child memorizes the equation in mathematics because of memorizing it in the story or by watching his classmate, i.e. [22]. The child learns firmly in the mind [29; 30]. Play does not interfere with academic learning, and play does not slow down teaching [24]. Games can be built through real experiences that teach in a deeper way that children remember and understand faster and easier [27]. So that children move from one fun activity to another, and teachers move away from traditional activities [31].

Learning based on useful play should be in the classroom, especially in kindergarten [28]. Children's minds are deeper in focus and understanding when they play in learning [22]. The levels of interest and understanding during learning by playing are much deeper than pulling out a worksheet [29]. My Math Academy is a learning accelerator and adaptive math solution for kindergarten and first and second grades [32–33].

2.2 My Math Academy application

My Math Academy provides math content that is interesting to the child and is available for use at home and at school [22]. It focuses on basic concepts in mathematics: counting and comparing quantities, order of numbers, relationships in mathematics, addition and subtraction, facts in mathematics, place value of numbers [14]. My Mathematics Academy was built according to the mastery learning system (PMLS), and this system is of an individual nature in terms of use and instruction for the student. My math academy provides a guide to help with the application, to help young students to enable them to master Personal Environment Learning (PMLE). The design of My Math Academy consists of three components: face-to-face learning games for children, the second component for the parents, and the third component for the teacher [12]. Designed by My Math Academy, it contains 98 games and over 300 activities that cover concepts and skills in mathematics from kindergarten to Grade 2 [18]. My Math Academy relies on a child's diagnostic evaluation to determine appropriate games and activities for the child based on the child's prior knowledge. My Math Academy focuses on an adaptive system that uses assessment of student performance to learn the level of difficulty of the game they are assigned to [19]. Each of the six activities is designed with a graded level of difficulty according to a previously reviewed map of learning objectives [22]. According to children's skills and understanding, they move to the next game level [23]. The problem of the study revolves around that in Jordan, as in all countries, we need to know the validity of the use of computer games application of the mathematics academy to learn mathematics for early learning students in Jordan. It is one of the most important technologies that needs to highlight its impact on students, and this raises the central question in this study: Is there an effectiveness in applying My Math Academy computer games to learn mathematics on the academic achievement of early education students in Jordan?

3 METHODOLOGY

This research used the procedural model design (definition, design, development, and distancing) for the research. [20] is the basis of this developmental research and refers to using My Math Academy app development model with the goal of developing for learning and mastering.

3.1 The study sample

The components of the study sample that the researcher relied on in his study consisted of kindergarten students and the first and second grades in the city of Amman during the academic year 2022/2023 during the first and second semesters from eight schools. They were divided into two groups, the therapeutic group, consisting of 505 students, and the control group that consisted of 481 students. The study sample included kindergarten students, divided into 233 students in a treatment group and 252 students in a control group, with a total of 485 students (see Table 1).

Table 1. Components of the study sample

	Treatment	Control	Total
Kindergarten	233	252	485
1st & 2nd grades	219	182	401
Total	452	434	886

The first- and second-grade remedial group was divided into 219 students in a treatment group and 182 students in a control group, for a total of 401. Students in the remedial group were gradually trained to use My Math Academy as a resource for learning and supporting understanding of mathematics. Starting at 8% in the first month, with a monthly increase of 10%, we have reached a usage rate of approximately 80%.

3.2 Instrument and data collection

The questionnaires were used in this research, as a research tool, and were designed according to Likert scale [5]. The questionnaire of educational experts focused on two parts: the content in mathematics provided to students through electronic games, and the interaction interface of the application and the display of activities during each game. As for the questionnaires for teachers and students, they focused on measuring the applied aspect according to the following indicators: effectiveness, interaction, efficiency, and creativity index [10]. Before the data collection process, the validity of the questionnaires was verified by three experts (experts in learning mathematics, experts in learning technology, and experts in educational technologies). To test the validity of the content used, the three experts reviewed the validity of the application. To collect data, a questionnaire was distributed to the participating teachers. As for the practical test that was applied to students who It was selected by taking an experimental sample, which showed an improvement in the level of students.

Prior to implementation, participating teachers were trained in a 2-hour virtual My Math Academy application, with time-lapse videos (3 to 9 minutes) focused on students applying for the first time in My Math Academy, and on a teacher dashboard showing how to engage with the student's electronic account and the use of the electronic whiteboard by default in the first month to acquire the skill of identifying students' previous knowledge through my mathematics academic assessments, and to develop the skills of using the teacher's information board, and the method of monitoring students' progress. The researcher held an extensive discussion with the participating teachers periodically during the year to learn about developments and answer teachers' questions and observations from the field during application. Teachers participated in using My Math Academy for 45 minutes during the week spread over 5 days (9 minutes per class). The school relied on computers, students' iPads, computers, and students' cellular devices that had My Math Academy app installed on them, and students used their individual accounts to access the app while at school or at home. At the end of the 2022/2023 school year, teachers were asked to fill out a questionnaire, conduct assessments, and conduct an interview that included questions about the teachers' experiences with My Math Academy app. In the study, measures and sources were used to collect data as follows: Assessment of students' achievement in mathematics learning, where a measurement tool developed by researchers was used to evaluate students.

The math student assessments that used My Math Academy were determined by the math objectives for the age group of the participating students. The pre-assessment process included 31 multiple-choice choices. The duration of the test was 30–45 minutes. For the post-test, it was modified to include 7 additional items targeting the Grade 2 Math standards due to students making significant progress in the preliminary test. The duration of the post-test was 45 minutes. For kindergarten students, each student was allowed to stop after completing 31 items to consider the age group. The evaluation process took place at the beginning of the academic year 2022–2023 in the month of September 2022. After applying the use of My Math Academy in the classroom, an evaluation was conducted in the form of small groups of students (5–6 students). Technical support was provided to students, such as assistance in login and any problems related to the use of devices, whether it is a computer, mobile phone, computer or iPad, and headphones were used for each student to give instructions. For each component of the evaluation, questions were answered by clicking to select a file on the screen. It is ensured that students have answered all questions before submitting. Code 0 (correct answer) or code 1 (correct answer) was used. Periodic visits were made during the academic year for the academic year 2022–2023. It is observed that many students have made great progress in using it. Especially in Grade 2 Math, remedial group teachers were asked to apply My Math Academy for three sessions of 20 minutes each per week (an hour per week) as a complementary resource to the math curriculum. The total educational activities were evaluated through games during the application of My Math Academy according to multiple variables that include students' performance in the game that was previously chosen and determined according to the student's abilities and age stage, and each game was associated with one or more goals to acquire skills, for example, adding and subtracting numbers from 1–9, counting skill for numbers from 1–30; in addition to measuring student performance with graded difficulty levels for each game. Teachers participating in My Math Academy app were surveyed according to monitoring of classroom practices and activities of teachers participating during My Math Academy app. Prior to the study, the participating teachers were asked to provide information regarding their practices and activities during implementation. They were limited to a survey before the study with 21 treatments associated with 19 controls, and a survey at the end of the study of 21 treatments associated with 20 controls. The teachers gave feedback about their practices and activities, including observations about the use of technological tools, and skills in mathematics such as counting 1–99, addition and subtraction two and three numbers according to the target age group.

Their observations were limited to a pre-study survey with 21 treatments associated with 19 controls, and a survey at the end of the study with 21 treatments associated with 20 controls. Teachers' feedback included monitoring students' interest in learning mathematics, using a Likert scale of 1–5, where 1 stands for very negative, 2 negative, 3 neutral, 4 positive, and 5 extremely positive. Among the teachers' observed statements were "I feel very at ease using My Math Academy as a math tutor, especially when teaching new skills to students" and "I find using My Math Academy to be a useful and supportive resource for learning mathematics, which is fun and engaging for students". These statements are translated into a questionnaire coded on a Likert scale. On a scale of 1 to 4, where 1 strongly disagree, 2 disagree, 3 agree, and 4 strongly agree, data were analyzed using SPSS software. Teachers from both the treatment groups (8) and the control group (4) were interviewed. The interview with the teacher focused on observations about the extent of my math academy application, obstacles encountered, how well students interacted during my math academy application, and inquiries about the teacher's role while applying as a mentor and evidence and supportive as well as focusing on the class environment in general. To identify the applications used in digital mathematics, the researcher used the monitoring protocol using the log file. Three areas were monitored: classroom management, teaching quality, and play quality. An inter-evaluator reliability score of 0.89 was calculated.

3.3 Data analysis

A basic equivalence test was performed using pre- and post-matched samples. There were no statistically significant differences to estimate the effect of My Math Academy on student outcomes between the treatment group and the control group at baseline. See Table 2.

Table 2. Baseline differences on the pretest scores with 31 items

Adjusted Means						
Study Sample	Treatment (SD)	Control (SD)	Difference (SE)	p-Value 95%	Confidence Interval	Unweighted Student Sample Size
Pre- and post-matched sample	15.38 (6.97)	15.53 (6.80)	–0.16 (0.60)	0.794	–1.34 to 1.02	886
Baseline sample for random assignment	15.46 (6.98)	15.54 (6.79)	–0.09 (0.59)	0.875	–1.2 to 1.07	918

4 RESULTS AND DISCUSSION

4.1 Results and discussion the effect of My Math Academy on student math achievement

The scores for student performance in mathematics showed that My Math Academy app improved student achievement in mathematics, as measured by a researcher-developed math assessment. In particular, the treatment group used My Math Academy for 12–13 weeks, compared to the control group. The difference between the treatment group and the control group was small and statistically significant (effect size = 0.11, p. = 0.026). It is the effect size that is considered moderate. This may be due to the use of digital applications by teachers of the control group other than My Math Academy, which may have been like them in influence during the three months when the application was implemented. This indicates the positive impact of using My Math Academy despite the competition with other teachers. Applications have a positive effect, subgroup analysis showed that the effect of the program varies according to the degree. It was observed in kindergarten that the treated group scored a point higher than the control group, with a statistically significant difference of 20.14 vs. 19.23, p = 0.01, effect size = 0.16. In the first grade, the difference between the treatment group and the control group decreased. My Math Academy affected a student's academic achievement in mathematics * p < .05, adjusted (see Table 3).

Table 3. The effect of My Math Academy on student math achievement

Adjusted Means						
Outcome Measure	Treatment (SD)	Control (SD)	Difference (SE)	p-Value	Effect Size	Unweighted Student Sample Size
Post-test (38 items)	20.97 (8.01)	20.08 (7.84)	0.89* (0.40)	0.026*	0.11	922

Note: *p < .05.

4.2 Results and discussion: effect of My Math Academy on the most advanced skills assessed

The treatment group using my math academy gained 20.2 points compared to the control group, 19.1 points, p = 0.01, effect size = 0.16, in kindergarten as learning gains. While there are no statistically significant differences between the treatment group for the first and second grades and the control group for the first and second grades, this confirms that the effect of the group that used My mathematics academy in kindergarten is greater than the effect in the first and second grades. Kindergarten students excelled in the most difficult skills that were evaluated. These skills were added to the post-test in kindergarten after it was noticed during the application that kindergarten children excelled until they were able to deal with second-grade games (see Figure 1).

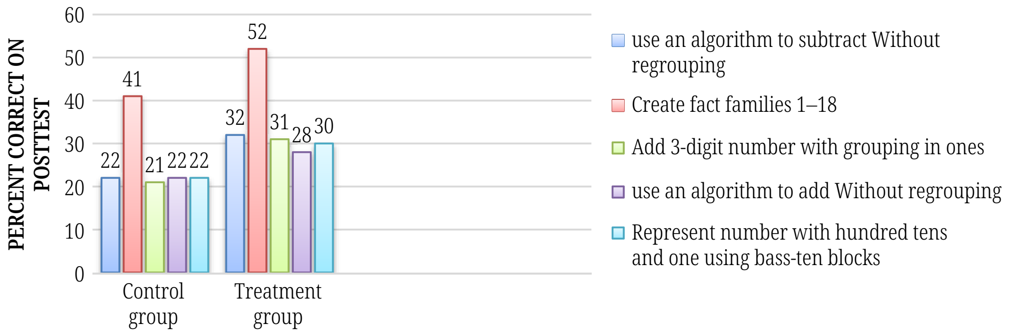

Fig. 1. Effect of My Math Academy on the most advanced skills assessed

To see if My Math Academy was associated with math skill development as measured by assessment where we examined the relationship between math skill development and post-test score. The correlation between the post-test score and the number of cumulative skills mastered by students in My Math Academy was strong at r = 0.73 (see Figure 2).

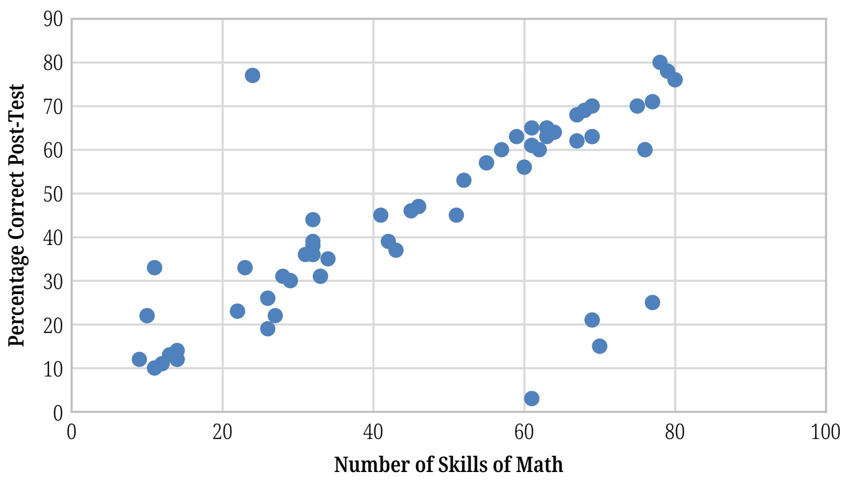

Fig. 2. Correlation, $p < 0.01$ between the skills students master through My Math Academy and their post-test scores r = 0.73

4.3 Results and discussion teachers' perception of educational technology on their students' math skills

The survey at the end of the study confirmed that the teachers in the treatment group (n = 20) and the control group (n = 20) answered questions about the positive and significant effect of using technology on the mathematical skills of their students (see Figure 3).

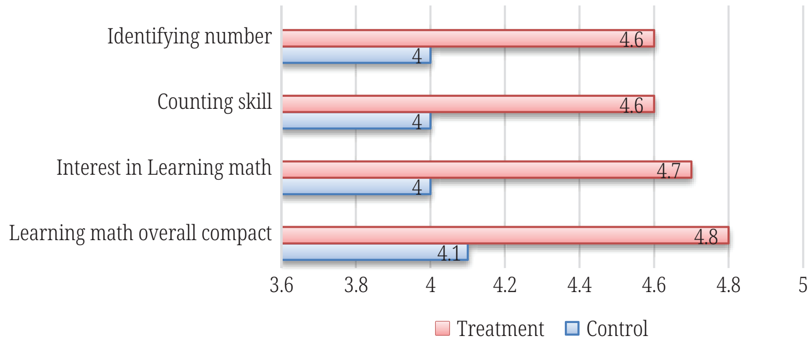

Fig. 3. Teachers' perception of educational technology on their students' math skills

In the interview, one of the teachers said: "I am a kindergarten teacher. It is great that children learn through the activities of My Math Academy, which provides them with more activity and interest in the classroom environment. Learning mathematics becomes fun and students acquire skills faster." One of the teachers explained: "The students use their mobile devices. They are professional in the activities, and they are very interested. They share their experiences by playing to learn mathematics among themselves." (See Figure 4)

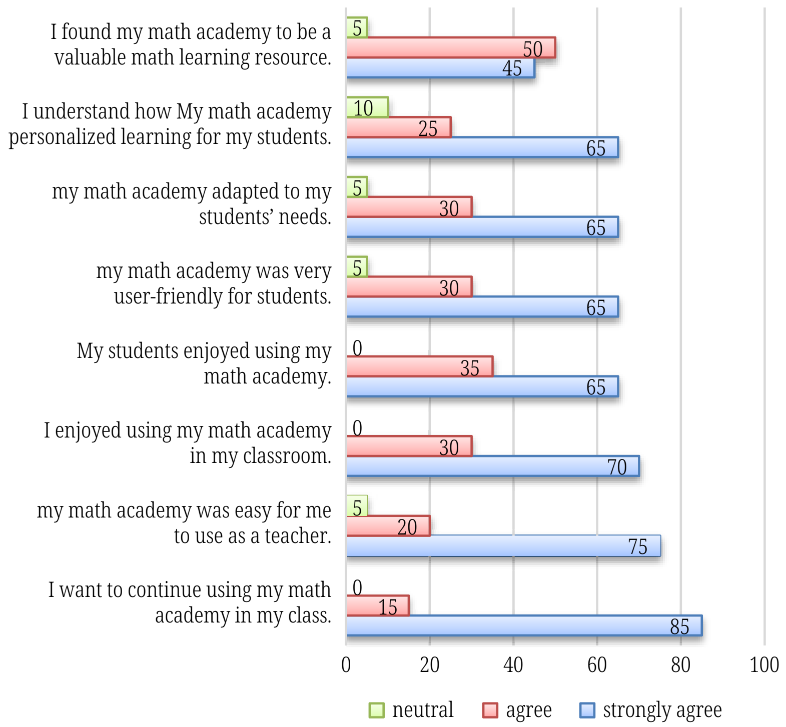

Fig. 4. Treatment teachers' experiences of using My Math Academy in their classrooms

This study stresses the need to develop early childhood education practices [19]. It emphasizes the importance of play in helping young students build personal academics based on appropriate game-based learning for young students. The results of the study indicated that students in the treatment group who used My Math Academy for a period of 12 weeks in 2022–2023 outperformed students in the control group in mathematics achievement. This result is particularly remarkable because students learn self-directed play within My Math Academy, without the need for rote learning and memorization. Moreover, stimulation for children, learning personally and learning to master are some of the most important features of My Math Academy. Teachers confirmed that my math academy app alleviates the challenges in learning math for young children [15]. The results indicate that My Math Academy provides customized guidance to students who have problems understanding mathematics, especially in skills that are overlooked by kindergarten teachers who focus most of the time on basic skills (shape, countdown, numbers…). Finally, the findings of this study are consistent with a 2017 study of pre-kindergarten and kindergarten classrooms that used My Math Academy over a 12–14-week period [7] and increase students' interest in learning mathematics. My Math Academy is a promising and effective intervention for students from poor and low-income families, to help reduce the gap in mathematics knowledge.

4.4 Limitations and future research

The use of more than one game application for learning mathematics in kindergarten in the treatment group by teachers hinders knowledge of the real impact of using the My Math Academy application. Another limitation is time, which is overcome by the teachers' persistence and constant interaction with My Math Academy. As for the relationship between My Math Academy and the use of abstract number games, it can negatively affect it in terms of its competition and in terms of its attractiveness. This requires developing games and activities that are highly engaging and complementary to the mathematics curriculum at the same time.

5 CONCLUSIONS

The results of this study were consistent with study [22], which found positive effects of using My Math Academy for pre-kindergarten and kindergarten classes over a 14-week period. My Math Academy version of this study included games for 1st and 2nd grade content. The results of this study showed that the control group that used the second-grade content app outperformed the control group, indicating that the positive effects of using My Math Academy extend beyond kindergarten. As for teachers' positive perception of my mathematics academy in this study, this is due to the app's ease of use and students' high engagement in the app to learn math. The results of this study reinforce and clarify previous evidence [22], confirming the effectiveness of My Math Academy in teaching mathematics to young learners, as well as the app's usability in first and second semesters. It has two features, play and master the games. This app turns out to be very practical according to teachers and students. It is applicable to mathematics. This study concluded that the application of computer games in My Math Academy for learning mathematics resulted in a significant improvement in the academic achievement of early learning students in Jordan. These positive trends are not only among students, but also among teachers and parents who appreciate the positive impact of learning through electronic games. My Math Academy computer games app provides the opportunity for parents to share games and activities with their students while learning through this app. The intended future research is to test these game-based applications in different educational stages.

6 REFERENCES

[1] Malik, S. I., Al-Emran, M., Mathew, R., Tawafak, R. M., & AlFarsi, G. (2020). Comparison of E-learning, M-learning and game-based learning in programming education. Int. J. Emerg. Technol. Learn., vol. 15, no. 15, pp. 133–146. https://doi.org/10.3991/ijet.v15i15.14503

[2] Umang, D., & Jain, N. (2020). Teaching assessment tool: Using AI and secure techniques. International Journal of Education and Management Engineering, vol. 10, no. 3, pp. 12–21. https://doi.org/10.5815/ijeme.2020.03.02

[3] Natt Avud Pimpa (2011). Engaging international business students in the online environment. The International Journal of Management Education, vol. 9, no. 3, pp. 77–89. https://doi.org/10.3794/ijme.93.323

[4] Inssaf El Guabassi, Mohammed Al Achhab, Ismail Jellouli, and Badr Eddine El Mohajir (2016). Towards adaptive ubiquitous learning systems. International Journal of Knowledge and Learning, vol. 11, no. 1, pp. 3–23. https://www.inderscienceonline.com/doi/10.1504/IJKL.2016.078653

[5] Mohd Shafie Rosli, Nor Shela Saleh, Baharuddin Aris, Maizah HuraAhmad, and Shaharud-din Md Salleh (2016). Ubiquitous hub for digital natives. International Journal of Emerging Technologies in Learning (iJET), vol. 11, no. 02, pp. 29–34. https://doi.org/10.3991/ijet.v11i02.4993

[6] Abu Mukh, Y. N., Hashaikeh, S. A., & Abd-Rabo, A. M. (2021). Digital Learning Games Scale (DLGS): A scale development study. Int. J. Emerg. Technol. Learn., vol. 16, no. 11, p. 140. https://doi.org/10.3991/ijet.v16i11.20709

[7] Malik, S. I., Al-Emran, M., Mathew, R. Tawafak, R. M., & AlFarsi, G. (2020). Comparison of Elearning, M-learning and game-based learning in programming education. Int. J. Emerg. Technol. Learn., vol. 15, no. 15, pp. 133–146. https://doi.org/10.3991/ijet.v15i15.14503

[8] Juric, P., Bakaric, M. B., & Matetic, M. (2021). Motivational elements in computer games for learning Mathematics. Int. J. Emerg. Technol. Learn., vol. 16, no. 10, pp. 275–287. https://doi.org/10.3991/ijet.v16i10.20417

[9] Yoon, C. S. & Khambari, M. N. M. (2022). Design, development, and evaluation of the robobug board game: An unplugged approach to computational thinking. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 06 SE-Papers, pp. 41–60. https://doi.org/10.3991/ijim.v16i06.26281

[10] Syahidi, A. A., Supianto, A. A., & Tolle, H. (2019). Design and Implementation of Bekantan Educational Game (BEG) as a Banjar Language Learning Media. International Journal of Interactive Mobile Technologies (IJIM), vol. 13, no. 03 SE-Papers, pp. 108–124. https://doi.org/10.3991/ijim.v12i7.9257

[11] Hariadi, B., Sunarto, M. J. D., Sagarin, T., Prahani, B. K., & Jatmiko, B. (2021). Higher order thinking skills for improved learning outcomes among Indonesian students: A Blended Web Mobile Learning (BWML) Model. International Journal of Interactive Mobile Technologies, vol. 15, no. 7, pp. 4–16. https://doi.org/10.3991/ijim.v15i07.17909

[12] Sarifah, I., Romania, A., Marini, A., Sagita, J., Nuraini, S., Safitri, D., Maksum, A., Suntari, Y., & Sudrajat, A. (2022). Development of android based educational games to enhance elementary school student interests in learning mathematics. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 18 SE-Papers, pp. 149–161. https://doi.org/10.3991/ijim.v16i18.32949

[13] DeMara, R. F., Tian, T., & Howard, W. (2021). Longitudinal learning outcomes from engineering-specific adaptions of hybrid online undergraduate instruction. International Journal of Emerging Technologies in Learning (IJET), vol. 16, no. 23, pp. 171–201. https://doi.org/10.3991/ijet.v16i23.17615

[14] Elmira, O., Rauan, B., Dinara, B., & Prevalla Etemi, B. (2022). The effect of augmented reality technology on the performance of university students. International Journal of Emerging Technologies in Learning (IJET), vol. 17, no. 19 SE-Papers, pp. 33–45. https://doi.org/10.3991/ijet.v17i19.32179

[15] Carrion Silva, A. J., Reyes Calderon, A. M., Giraldo Retuerto, M., & Andrade-Arenas, L. (2022). Application of augmented reality in teaching and learning in engineering programs. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 15 SE-Papers, pp. 112–124. https://doi.org/10.3991/ijim.v16i15.31695

[16] Daineko, Y., Tsoy, D., Ipalakova, M., Kozhakhmetova, B., Aitmagambetov, A., & Kulakayeva, A. (2022). Development of an interactive mobile platform for studying radio engineering disciplines using augmented reality technology. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 19 SE-Papers, pp. 147–162. https://doi.org/10.3991/ijim.v16i19.32373

[17] Hamzah, M. L., Ambiyar, A., Rizal, F., Simatupang, W., Irfan, D., & Refdinal, R. (2021). Development of augmented reality application for learning computer network device. International Journal of Interactive Mobile Technologies (IJIM), vol. 15, no. 12 SE-Papers, pp. 47–64. https://doi.org/10.3991/ijim.v15i12.21993

[18] Asmianto, Hafiizh, M., Rahmadani, D., Pusawidjayanti, K., & Wahyuningsih, S. (2022). Developing android-based interactive E-modules on trigonometry to enhance the learning motivation of students. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 02 SE-Short Papers, pp. 159–170. https://doi.org/10.3991/ijim.v16i02.27503

[19] Zain, F. M., Sailin, S. N., Kasim, M., Abdul Karim, A. M., & Zameri, N. N. (2022). Developing an Augmented Reality Immersive Learning Design (AILead) framework: A fuzzy Delphi approach. International Journal of Interactive Mobile Technologies (IJIM), vol. 16, no. 11 SE-Papers, pp. 65–90. https://doi.org/10.3991/ijim.v16i11.30063

[20] Suprapto, N., Nandyansah, W., & Mubarak, H. (2020). An evaluation of the "PicsAR" research project: An augmented reality in physics learning. International Journal of Emerging Technologies in Learning, vol. 15, no. 10, pp. 113–125. https://doi.org/10.3991/ijet.v15i10.12703

[21] Zourmpakis, A.-I., Papadakis, S., & Kalogiannakis, M. (2022). Education of preschool and elementary teachers on the use of adaptive gamification in science education. International Journal of Technology Enhanced Learning, vol. 14, no. 1, pp. 1–16. https://doi.org/10.1504/IJTEL.2022.120556

[22] Ahmed Al-Hunaiyyan, Salah Al-Sharhan, and Rana Alhajri (2017). A new mobile learning model in the context of smart classroom environment: A holistic approach. International Journal of Interactive Mobile Technologies, vol. 11, no. 3. https://doi.org/10.3991/ijim.v11i3.6186

[23] Thai, K. P., Li, L., & Schachner, A. (2018). My Math AcademyTM significantly accelerates early mathematics learning. Age of Learning Research Brief. Retrieved from: https://www.ageoflearning.com/case_studies/MMA-Research- rief_2018_UPDATE_06.pdf

[24] Hamzah, N., Abd Halim, N., Hassan, M., & Ariffin, A. (2019). Android application for children to learn basic solat. International Journal of Interactive Mobile Technologies, vol. 13, no. 7. https://doi.org/10.3991/ijim.v13i07.10758

[25] El-Sofany, H. & El-Haggar, N. (2020). The effectiveness of using mobile learning techniques to improve learning outcomes in higher education. International Journal of Interactive Mobile Technologies, vol. 14, no. 8. https://doi.org/10.3991/ijim.v14i08.13125

[26] Kozik, T. & Handlovska, I. (2011). The reduction of interest among elementary students in the field of technical education. International Journal of Engineering Pedagogy (iJEP), vol. 1, no. 3, pp. 9–12. https://doi.org/10.3991/ijep.v1i3.1822

[27] Erazo-Palacios, J., Jaimez-González, C. R., & García-Mendoza, B. (2022). Towards a web generator of programming games for primary school children. International Journal of Engineering Pedagogy, vol. 12, no. 4. https://doi.org/10.3991/ijep.v12i4.17335
[28] Záhorec, J., Hašková, A., & Munk, M. (2018). Particular results of research aimed at curricula design of teacher training in the area of didactic technological competences. International Journal of Engineering Pedagogy (iJEP), vol. 8, no. 4, pp. 16–31. https://online-journals.org/index.php/i-jep/article/view/8184
[29] Kuna, P., Hašková, A., Palaj, M., Skačan, M., & Záhorec, J. (2018). How to teach CAD/CAE systems. International Journal of Engineering Pedagogy (iJEP), vol. 8, no. 1, pp. 148–162. https://doi.org/10.3991/ijep.v8i1.8185
[30] Ismail, H. M., Balkhouche, B. & Harous, S. (2020). Data for information Wikisto evaluate informal learning. International Journal of Engineering Pedagogy (iJEP), vol. 10, no. 1. https://doi.org/10.3991/ijep.v10i1.11713
[31] Kälberer, N. et al. (2014). Preparatory mathematics course for non-traditional engineering students. International Journal of Engineering Pedagogy (iJEP), vol. 4, no. 4, pp. 51–58. https://doi.org/10.3991/ijep.v4i4.3999
[32] Zaher, A. A. & Damaj, I. W. (2018). Extending STEM education to engineering programs at the undergraduate college level. International Journal of Engineering Pedagogy (iJEP), vol. 8, no. 3, pp. 4–16. https://doi.org/10.3991/ijep.v8i3.8402
[33] Fessakis, G., Karta, P., & Kozas, K. (2018). Designing math trails for enhanced by mobile learning realistic mathematics education in primary education. International Journal of Engineering Pedagogy (iJEP), vol. 8, no. 2, pp. 49–63. https://doi.org/10.3991/ijep.v8i2.8131
[34] Handoyo, L. D., & Listiyarini, I. Y. (2018). Development of character assessment instruments in service-learning at biology education department Sanata Dharma University. International Journal of Indonesian Education and Teaching, vol. 2, no. 1. https://doi.org/10.24071/ ijiet.v2i1.960

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PAPER

Changing Mathematical Paradigms at the University Level: Feedback from a Flipped Classroom at a Peruvian University

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ABSTRACT

The university-level mathematics teaching adopted by many professors is still a traditional classroom, and many students' perception of mathematics is that it is a complicated subject. The operationality of the flipped classroom proposal implemented at a university has a potential that can be used to change the perception that university students and teachers have towards the mathematics course, as well as to change the methodology of many teachers on how they teach their courses in the classroom. This research is the result of the implementation of the flipped classroom methodology in the basic mathematics course that is part of the professional careers of the engineering faculty of a Peruvian university. The aim of this study was to analyze the impact of applying the flipped classroom on academic results and attitudes towards mathematics, with an experimental group of 227 students and a control group of 215 students. The academic results were measured at each of the stages indicated in the course syllabus, T1, partial exam, T2 and final exam; attitudes towards mathematics were also assessed at cognitive, procedural and affective levels at the end of the university semester. The Kolmogorov-Smirnov normality test was applied and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution. With the data obtained, the Mann-Whitney U test was performed, obtaining a $p = 0.00$ value ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ makes us conclude that there are statistically significant differences between the scores of the experimental group compared to the control group. The results show a significant improvement in the academic performance and positive attitudes of students who took the course using the flipped classroom compared to those who did not use this methodology.

KEYWORDS

academic performance, flipped classroom, students' attitudes, university level

Beltozar-Clemente, S., Iparraguirre-Villanueva, O., Zapata-Paulini, J., Cabanillas-Carbonell, M. (2023). Changing Mathematical Paradigms at the University Level: Feedback from a Flipped Classroom at a Peruvian University. *International Journal of Engineering Pedagogy (iJEP)*, 13(6), pp. 76–89. https://doi.org/10.3991/ijep.v13i6.40763

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1 INTRODUCTION

Understanding mathematics is a challenge for many university students, as mathematics often involves abstract concepts that can be difficult to visualize or relate to real-world situations [1]. For this reason, many university students perceive the mathematics course as a difficult subject, with difficulties often attributed to a lack of preparation, practice and knowledge that would give the student the ability to solve a mathematical problem [2]. This ability should not only focus on the ability to solve a problem as a tool to practice procedures [3] but should become the means to connect mathematical work to everyday life by contextualizing the content through real problems that arise in everyday academic and professional situations [4]. This perception is reflected in poor academic results among students [5], as well as a lack of interest and motivation for mathematics among university students [6].

Many teachers feel that the use of technology in the classroom is detrimental to students' assimilation of knowledge and skills [7]. So, the mathematics teaching adopted by many teachers remains traditional [8], offering little chance for students to acquire the ability to solve real mathematical problems. This approach does not meet students' individual learning needs, leading to a lack of interest in mathematics [9], and even more so when many students had to adapt to an online learning environment due to COVID 19, which presented additional challenges for learning mathematics [10].

Advances in information and communication technologies are making it possible to promote new forms of teaching in university classrooms, opening up spaces for the democratization of knowledge [11]. Several methodologies used at university level encourage a shift from traditional to more participatory teaching, involving students in the construction of their own knowledge and generating positive impacts on their academic performance and attitudes [12]. One of the methodologies with the greatest impact on the teaching and learning process is the flipped classroom, which has an advantage over other active methodologies in terms of improving academic performance and attitudes to mathematics; this method also presents the challenge of involving more asynchronous student participation in different activities [13, 14].

The flipped classroom is a pedagogical model [15] in which the student accesses knowledge autonomously outside the classroom, practicing and questioning content in different ways, with this entire sequence of activities carefully prepared by the teacher [16]. It moves the activities that traditionally took place in the classroom to the physical space where the student is located, enabling the teacher to interact more actively with students and identify their cognitive and procedural needs when solving a mathematical problem [17]. Implementation of the flipped classroom in university teaching has increased in recent years, showing significant progress at procedural, attitudinal and cognitive levels in students who have developed the method [18]. However, there is little research showing macro-level implementation of the flipped classroom across an entire university semester in the Faculty of Engineering's Professional Studies program [19].

The most recent research on the flipped classroom shows that it has been used in several disciplines with encouraging results, becoming a determining factor in the success of student learning, as students work actively and collaboratively, being the builders of their own knowledge, enabling the teacher to guide the process effectively [20, 21]. COVID 19 had a significant impact on the perception and adoption of the flipped classroom model, as all educational institutions had to adapt to the distance model during the pandemic [22]. Among the favorable perceptions identified here are greater acceptance of online learning as it promotes autonomous learning with anytime access to educational resources [23], flexible schedules, greater virtual interaction and accelerated adoption of technological tools [24]. This has motivated the accelerated transformation of teaching practices in universities to motivate, engage and promote student success [25].

The aim of this research is to determine the impact of the application of the flipped classroom on the academic results and attitudes at the cognitive, procedural and affective levels of students enrolled in the basic mathematics course in the different careers of the engineering faculty of a Peruvian university.

The remainder of this document is organized as follows. Section 2 presents an in-depth review of the literature relevant to the questions raised. Section 3 details the materials and methods used. The main results are presented in Section 4 and discussed in Section 5. Finally, Section 6 presents the main conclusions of the study, as well as research perspectives.

2 RELATED WORK

Focusing on the effectiveness and impact of the flipped classroom model, we highlight some of the most recent work on the following topics. The authors of [26] conducted a study on the influence of the flipped classroom in the scientific training of pre-service teachers, in which they highlight that the systematization of the flipped classroom significantly influences academic performance, attitudes and positive evaluation perspectives in their university training as teachers.

Similarly, [27] analyzed the influence of the flipped biochemistry classroom on students' academic performance and perceptions of self-awareness, obtaining the result that students who participated in the flipped classroom model achieved better academic performance ($p < 0.01$) and reported a significant improvement in their perceptions of self-awareness ($p < 0.01$) compared to the control group.

The authors of [28] demonstrated that the main factor influencing educational outcomes was self-efficacy, followed by gender, educational experience in the flipped classroom, satisfaction with learning, age, ability to analyze the flipped classroom and ability to analyze the flipped classroom.

Similarly, the authors of [29] conducted systematic reviews with the aim of evaluating the application and effectiveness of the flipped classroom in the training of nursing students. After reviewing 25 articles, they concluded that the model has three key elements: pre-class activities, in-class activities and post-class activities, which, when properly guided, generate positive learning in terms of skills, knowledge and attitudes in nursing students.

In [30], the authors conducted a meta-analysis on the application of the flipped classroom in mathematics courses. After reviewing 86 articles, they concluded that the application of the method improved mathematics learning in several aspects, such as academic achievement, active participation, motivation, interest and interaction between students and teachers.

3 MATERIALS AND METHODS

3.1 Research background

The research proposed in this article is part of the Fundamental Mathematics course, which is part of the Faculty of Engineering's pathways. The implementation of the flipped classroom methodology was developed over the 16 weeks corresponding to the entire two semesters of the 2021–2022 academic year. A whole team of specialist teachers designed the operational part of the flipped classroom methodology in the course in question, and the final proposal was implemented in 2022.

Figure 1 shows a diagram of the flipped classroom implemented in the basic mathematics course. Students first examine the course material in the virtual classroom, then take a knowledge test. Once they have completed these activities, they actively participate in the development of the course.

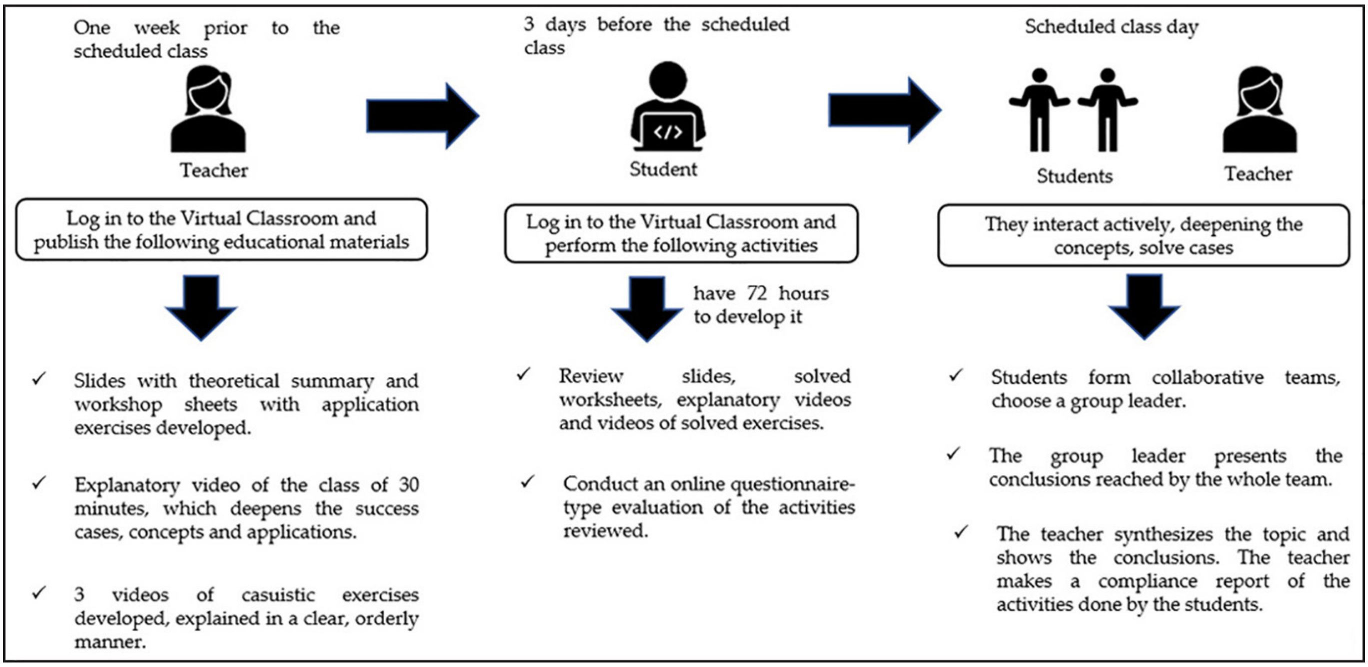

Fig. 1. Implementation of the flipped classroom

The basic mathematics course is divided into two units: linear algebra and limits. Students are required to take interim assessments in both semesters and a final assessment at the end of the second semester. Each student must have an average grade of 12 or above to pass the course. The Blackboard Collaborate platform was used to set up the virtual classroom where students can access asynchronous resources such as explanatory videos of the course, extended video exercises, slides with theoretical summaries of the material, and worksheets. There have been no updates to the career programs mentioned above; consequently, the themes developed are identical to those used during the two semesters of the 2020–2021 academic year. The same resources and materials were used in all sections during all sessions of the corresponding cycle. For research purposes, the 227 students enrolled in the two semesters of the 2020–2021 academic year constitute the control group. The 215 students enrolled in the two semesters of the 2021–2022 academic year constitute the experimental group.

Figure 2 shows a diagram of the academic resources designed and implemented in the virtual classroom of each of the classes where the flipped classroom was conducted. The resources were developed for the 16 weeks of the academic semester, the material (see Figure 2a) for each week consists of slides with theoretical summaries, worksheets of the exercises developed, an explanatory video of the class and videos of the exercises developed. Figure 2b shows the login message, the design of the learning session and the activities for testing learning using educational games.

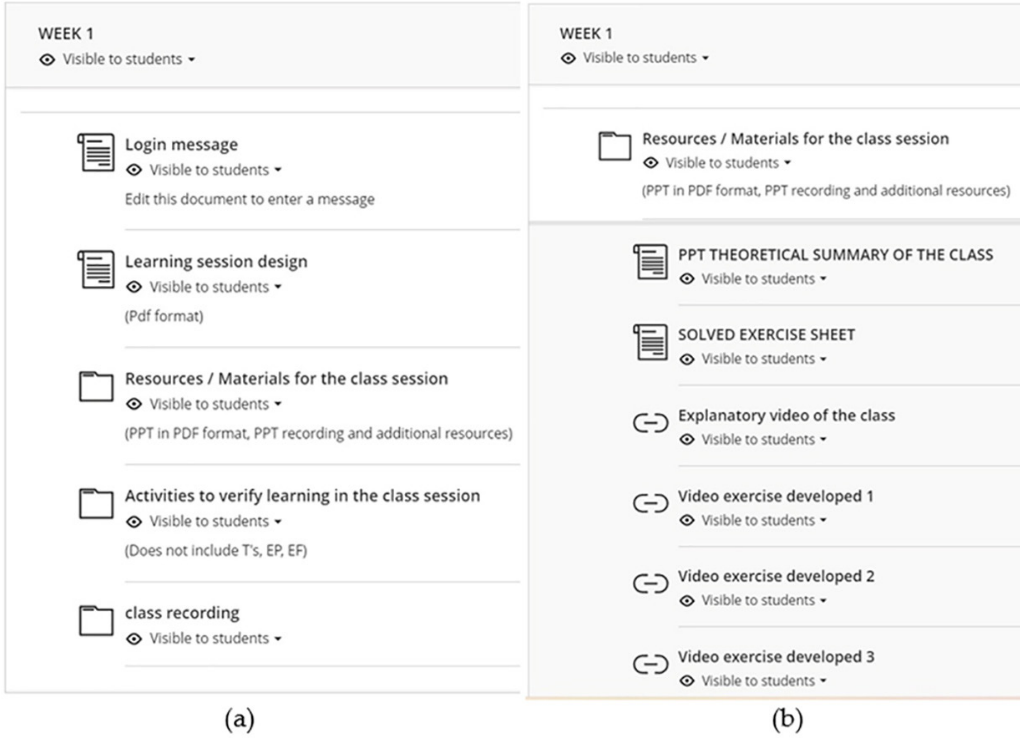

Fig. 2. Diagram of resources used: (a) Material for the session; (b) Resources sent in advance each week

Similarly, attitudes towards mathematics [31] were assessed at cognitive, procedural and attitudinal levels [32], in a questionnaire applied at the end of the academic semester. For each dimension, eight questions were asked, of which we can highlight some of the most frequent responses.

Figure 3 shows the diagram of the questionnaire on attitudes to mathematics at cognitive, procedural and affective levels. The questions with the most positive responses are shown below.

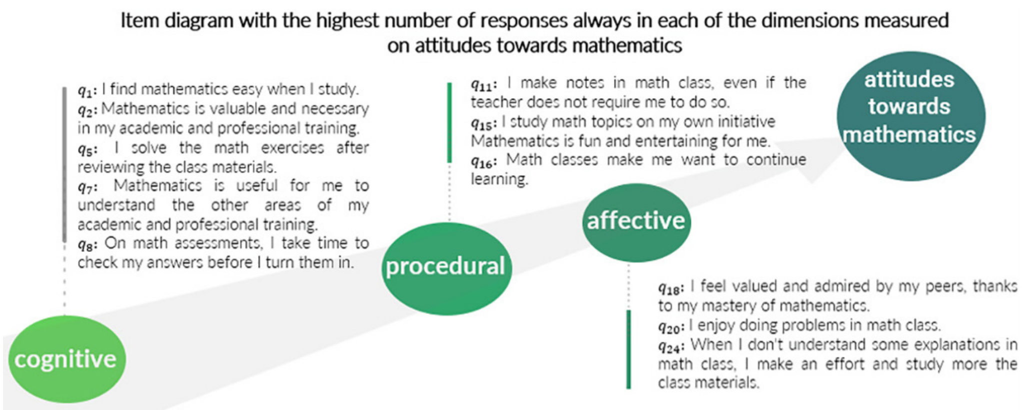

Fig. 3. Diagram of student attitude dimensions

3.2 Research design

This research was designed to be quasi-experimental [33]. The independent variable was the flipped classroom methodology, which framed the participants' asynchronous learning autonomy. The dependent variables were academic achievement and attitudes to mathematics.

To analyze the differences between students who used the flipped classroom methodology and those who did not, we compared the marks obtained in four assessments: two assessments graded T1 and T2, an intermediate exam and a final exam. These assessments were carried out during weeks 4, 8, 12 and 16, respectively, in accordance with the course syllabus that corresponds to the university's study plans. Similarly, at the end of the university semester, a Likert-scale questionnaire was conducted on students' cognitive, procedural and affective attitudes.

3.3 Data collection procedure

Measurement of academic results. The aim was to measure the impact of the flipped classroom on the academic results of students in the complementary mathematics course. Data were collected using the assessments defined above in accordance with the curricula for each course, for both the control (227 students) and experimental (215 students) groups. The results were analyzed using SPSS Statistics 26 [34].

Measuring student attitudes. The aim was to measure the impact of the flipped classroom on students' attitudes to mathematics. To this end, the research team developed and applied a questionnaire on attitudes to mathematics at cognitive, procedural and affective levels at the end of the academic semester in each of the groups. The questionnaire consists of 28 questions, the first four of which are framed by the demographic profile of all participants, and the remaining 24 questions were divided into three blocks of 8 questions each to assess cognitive, procedural and affective attitudes. Each question was measured using a 5-point Likert-type [35] rating scale, where 1 = Never; 2 = Almost Never; 3 = Sometimes; 4 = Almost Always; 5 = Always.

The internal consistency test using Cronbach's alpha for items in the cognitive dimension was 0.801, for items in the procedural dimension 0.878, for items in the affective dimension 0.927, similarly, for all items we have an alpha of 0.950. As all alpha values are above 0.7, this Cronbach's alpha test proves that the data collected in the questionnaire are internally consistent and reliable [36].

4 MAIN RESULTS

4.1 Impact of the flipped classroom on the academic results

Once data collection was complete, the Kolmogorov-Smirnov normality test was carried out on the entire data set and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution [37].

Figure 4 shows the quantile-quantile (Q-Q) plot for the entire data set with a Pearson linear coefficient of determination of 0.68 ($R^2 = 0.68$). The results show that the scores clustered around the solid line are scattered relative to each other, indicating that the data do not have a normal distribution.

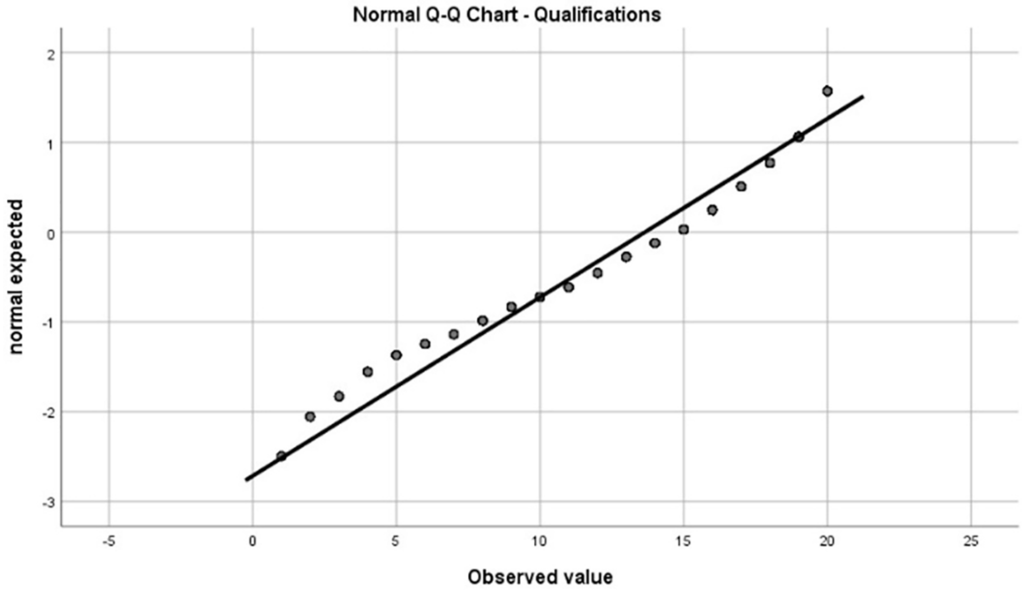

Fig. 4. Results of normality test (Q-Q plot) for the total data

As the data do not follow a normal distribution, a more practical non-parametric test was chosen to analyze the results. In this research, we used the Mann-Whitney *U* test [38], for which means, medians, standard deviations and variances were calculated for each of the T1, T2, partial and final assessments for both groups. To determine whether there was a significant difference between the two groups, a significance level of 0.05 or 95% reliability was established ($\alpha = 0{,}05_{2\ tails}$) with the aim of comparing the homogeneity of the data obtained.

Table 1 shows the results of the T1 evaluation. The control group obtained a mean of 14.61, a median of 16.00 and a standard deviation of 4.20. For this group, there were 19 missing data. The experimental group had a mean of 16.27, a median of 17.00 and a standard deviation of 3.85. For this group, there were 17 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining a value of $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced by the change in the weighting of positive attitudes towards the course, essentially in the procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 1. Analysis of academic results following the T1 evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	208	19	14.61	16.00	4.20	17.64
Experimental	198	17	16.27	17.00	3.85	14.84

Table 2 shows the results of the partial evaluation. The control group obtained a mean of 13.88, a median of 16.00 and a standard deviation of 4.64. Similarly, the experimental group obtained a mean of 15.65, a median of 16.00 and a standard deviation of 4.09, with 22 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 2. Analysis of academic results following the partial evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	204	23	13.88	15.00	4.64	21.50
Experimental	193	22	15.65	16.00	4.09	16.75

Table 3 shows the results of the T2 evaluation. The control group obtained a mean of 11.51, a median of 12.00 and a standard deviation of 5.254, with 31 missing data. The experimental group obtained a mean of 12.63, a median of 14.00 and a standard deviation of 4.980, with 26 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 3. Analysis of academic results following the T2 evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	196	31	11.51	12.00	5.25	27.60
Experimental	189	26	12.63	14.00	4.98	24.80

Table 4 shows the results obtained in the final evaluation, with the control group obtaining a mean of 10.20, a median of 10.00 and a standard deviation of 5.519, with 26 missing data. Similarly, the experimental group obtained a mean of 13.94, a median of 16.00 and a standard deviation of 4.812, with 31 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and affective level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 4. Analysis of academic results following the final exam

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	190	37	10.20	10.00	5.52	30.46
Experimental	184	31	13.94	16.00	4.81	23.15

4.2 Impact of the flipped classroom on student attitudes

Once the data collection was complete, the Kolmogorov-Smirnov normality test was carried out on the entire data set and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution [37].

Table 5 shows the percentage weights of the cognitive, procedural and affective dimensions of attitude for the control and experimental groups. For the cognitive dimension of attitude, there was a 7.86% decrease in the "Never" rating, a 21.15% decrease in the "Almost Never" rating and a 10.4% decrease in the "Sometimes" rating. Similarly, there was an 18.16% increase in the weighting of the "Almost Always" rating and a 21.35% increase in the "Always" rating. For the procedural attitude dimension, there was a decrease of 18.94% in the "Never" rating, 20.22% in the "Almost Never" rating and 1.89% in the "Sometimes" rating, as well as an increase of 21.00% in the "Almost Always" rating and 20.05% in the "Always" rating. For the affective attitude dimension, there was a decrease of 22.47% in the "Never" rating, 16.37% in the "Almost Never" rating, and an increase of 6.17% in the "Sometimes" rating, 17.66% in the "Almost Always" rating and 15.01% in the "Always" rating. It should be understood that the sustained increase in higher grades is due to the effect of implementing the flipped classroom in the basic mathematics course.

Table 5. Analysis of student attitudes by dimension

	Dimensions							
	Cognitive (%)		Procedural (%)		Affective (%)		Total (%)	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Never	8.79	0.93	20.16	1.22	27.45	4.98	18.80	2.37
Almost Never	26.25	5.00	28.61	8.39	25.68	9.31	26.85	7.56
Sometimes	39.52	29.12	37.26	35.37	35.82	41.99	37.50	35.47
Almost Always	14.32	32.48	8.34	29.34	8.46	26.12	10.37	29.32
Always	11.12	32.48	5.63	25.68	2.59	17.60	6.48	25.28

Figure 5 shows the evolution of the weighting of cognitive, procedural and affective attitudes towards mathematics of all students belonging to the control and experimental groups, confirming the differences or weighting margins in the assessments given to the group that implemented the flipped classroom. The results show that most of the students who took the basic mathematics course using the flipped classroom methodology improved the development of their attitudes towards mathematics in the cognitive, procedural and affective domains.

Analyzing the data obtained at inferential level, the Kolmogorov-Smirnov normality test was performed for the total number of answers given by students in the attitude questionnaire, yielding a value of $p = 0.00$, indicating that the total number of evaluations made by students does not follow a normal distribution. Next, the Mann-Whitney *U* test was performed, obtaining a value of $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ makes us conclude that there is a statistically significant improvement in the evaluations of attitudes towards mathematics at the cognitive, procedural and affective levels of the students who performed the flipped classroom.

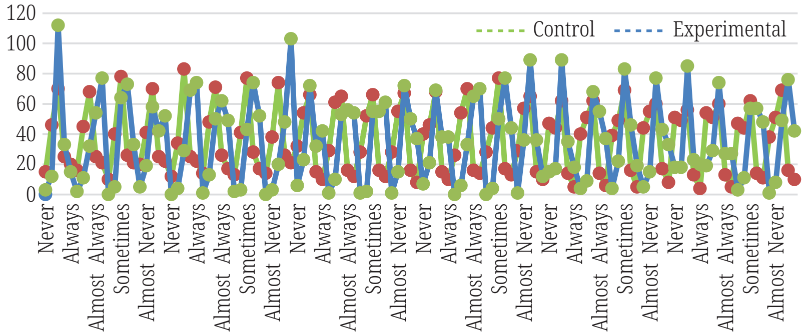

Fig. 5. Evolution of the weighting of cognitive, procedural and affective attitudes towards mathematics of all students belonging to the control and experimental groups

5 DISCUSSION

The aim of this study was to analyze the impact of the flipped classroom methodology on students' academic performance and attitudes in the basic mathematics course. This course is part of the professional careers of the engineering faculty of a Peruvian university. The academic results were measured at each of the stages indicated in the course syllabus, i.e. intermediate assessment T1, partial examination, intermediate assessment T2 and final examination. Similarly, attitudes towards mathematics were assessed at cognitive, procedural and affective levels by means of a questionnaire at the end of the academic semester.

The results of the study showed that implementing the flipped classroom in the basic mathematics course had a significant impact on improving students' academic performance. The results show a 2.07-point increase in the overall average grade of the group in which the flipped classroom was implemented, compared with the group that did not develop the methodology. These results are in line with those found in previous research on the application of the flipped classroom to improve students' academic performance in mathematics courses [39] in the same way [40].

The results also showed that the implementation of the flipped classroom had a positive impact on students' cognitive, procedural and affective attitudes towards mathematics. The results of the questionnaire conducted at the end of the semester showed that more students in the group that took the course with the flipped classroom methodology indicated that mathematics is useful and necessary for their professional academic training, they also mentioned that they study the course topics on their own initiative and that they enjoy learning in mathematics classes. In addition, after following the flipped classroom method, fewer students reported that mathematics was difficult. These results are consistent with those of previous studies on the application of the flipped classroom to improve students' attitudes to mathematics [41].

In conclusion, the students who took the basic mathematics course using the flipped classroom methodology achieved numerous benefits, not only improving their academic grades, but also strengthening their commitment to the development of the course and increasing their level of satisfaction at the end of the academic semester. Consequently, we can mention that the results obtained confirm the high potential of the flipped classroom methodology as a teaching and learning strategy, not only in mathematics courses, but also in other courses delivered as part of students' university education.

Among the limitations that emerged during the course of the research, we can mention that during the planning phase, we had little time to develop standardized material within the deadlines set by the university's teaching specialists, given that the teaching resources were used by all sections of the Faculty of Engineering. During implementation, as the flipped classroom largely requires the use of electronic equipment and access to the Internet, some students limited their participation because they did not have adequate access to these resources. It was also observed that many students are not able to manage their time for independent learning. Other limitations encountered are that even the way we assessed remained a traditional approach, which may not fully reflect the learning acquired through the flipped classroom.

6 CONCLUSIONS

The implementation of the flipped classroom elicited a positive response from the students and teachers who applied the methodology, as it enabled more participative interaction in the university classrooms, increased students' efficiency when solving the various problems in their assessments and also improved the attitudinal perception of the mathematics course. In conclusion, students who took the basic mathematics course using the flipped classroom methodology achieved numerous benefits, not only improving their academic grades, but also enhancing their engagement in the development of the course and increasing their level of satisfaction at the end of the university semester. Consequently, we can mention that the results obtained confirm the high potential of the flipped classroom methodology as a teaching and learning strategy, not only in mathematics courses, but also in other courses delivered as part of the academic training of university students.

Future work could firstly focus on updating the teaching materials used. Secondly, it might be interesting to replicate the procedural part of the flipped classroom, obtain results and find the correlation between academic performance and positive attitudes towards mathematics. Pearson's or Spearman's correlations could be used depending on the data obtained, and we could also apply this method not only to the Faculty of Engineering in later cycles, but also extend it to other specialties.

7 REFERENCES

[1] H. Uzunboylu, A. I. Prokopyev, S. G. Kashina, E. V. Makarova, N. V. Chizh, and R. G. Sakhieva, "Determining the opinions of university students on the education they receive with technology during the pandemic process," *International Journal of Engineering Pedagogy (iJEP)*, vol. 12, no. 2, pp. 48–61, 2022, https://doi.org/10.3991/ijep.v12i2.29329

[2] Y. Kaba and S. Şengül, "The relationship between middle school students' mathematics anxiety and their mathematical understanding," *Pegem Egitim ve Ogretim Dergisi*, vol. 8, no. 3, pp. 599–622, 2018, https://doi.org/10.14527/pegegog.2018.023

[3] M. Sharma, B. Sumaiya, K. K. Awasthi, and R. Mehrotra, "A framework for learning combined problem solving skills," *World Journal of English Language*, vol. 12, no. 3, pp. 10–17, 2022, https://doi.org/10.5430/wjel.v12n3p10

[4] la C. y la Cultura. Organización de las Naciones Unidas para Educación, "Aportes para la enseñanza de la matemática - UNESCO Biblioteca Digital," 2016. https://unesdoc.unesco.org/ark:/48223/pf0000244855 (Accessed: Dec. 05, 2022).

[5] F. Moradi and P. Amiripour, "The prediction of the students' academic underachievement in mathematics using the DEA model: A developing country case study," *European Journal of Contemporary Education*, vol. 6, no. 3, pp. 432–447, 2017, https://doi.org/10.13187/ejced.2017.3.432

[6] T. Kosiol, S. Rach, and S. Ufer, "(Which) Mathematics interest is important for a successful transition to a university study program?," *Int J Sci Math Educ*, vol. 17, no. 7, pp. 1359–1380, 2019, https://doi.org/10.1007/s10763-018-9925-8

[7] D. Thurm and B. Barzel, "Teaching mathematics with technology: A multidimensional analysis of teacher beliefs," *Educational Studies in Mathematics*, vol. 109, no. 1, pp. 41–63, 2022, https://doi.org/10.1007/s10649-021-10072-x

[8] X. Wang and H. Zhu, "Practice and exploration of higher mathematics teaching mode supported by Wechat public platform," *Lecture Notes in Electrical Engineering*, vol. 747, pp. 1695–1702, 2021, https://doi.org/10.1007/978-981-16-0115-6_197

[9] M. C. L. Huang et al., "Interest-driven video creation for learning mathematics," *Journal of Computers in Education*, vol. 7, no. 3, pp. 395–433, 2020, https://doi.org/10.1007/s40692-020-00161-w

[10] Z. Kanetaki, C. Stergiou, G. Bekas, C. Troussas, and C. Sgouropoulou, "Analysis of engineering student data in online higher education during the COVID-19 pandemic," *International Journal of Engineering Pedagogy (iJEP)*, vol. 11, no. 6, pp. 27–49, 2021, https://doi.org/10.3991/ijep.v11i6.23259

[11] C. M. Cardona-Londoño, E. Rivas-Trujillo, and M. Ramirez-Sánchez, "The horizon of higher education: ICT models and posnormal science," *Espacios*, vol. 40, no. 41, 2019.

[12] C. D. Smith and C. Baik, "High-impact teaching practices in higher education: A best evidence review," *Studies in Higher Education*, vol. 46, no. 8, pp. 1696–1713, 2021, https://doi.org/10.1080/03075079.2019.1698539

[13] G. Akçayır and M. Akçayır, "The flipped classroom: A review of its advantages and challenges," *Comput Educ*, vol. 126, pp. 334–345, 2018, https://doi.org/10.1016/j.compedu.2018.07.021

[14] M. Zappatore, "The immersive workbench for engineering educators: (Re)Thinking collaborative and distance learning platforms as technological enablers," *International Journal of Engineering Pedagogy (iJEP)*, vol. 11, no. 4, pp. 4–6, 2021, https://doi.org/10.3991/ijep.v11i4.25297

[15] J. O'Flaherty and C. Phillips, "The use of flipped classrooms in higher education: A scoping review," *Internet and Higher Education*, vol. 25, pp. 85–95, 2015, https://doi.org/10.1016/j.iheduc.2015.02.002

[16] D. N. Ventosilla Sosa et al., "Aula invertida como herramienta para el logro de aprendizaje autónomo en estudiantes universitarios," *Propósitos y Representaciones*, vol. 9, no. 1, 2021, https://doi.org/10.20511/pyr2021.v9n1.1043

[17] B. Del Río-Gamero, D. E. Santiago, J. Schallenberg-Rodríguez, and N. Melián-Martel, "Does the use of videos in flipped classrooms in engineering labs improve student performance?," *Educ Sci (Basel)*, vol. 12, no. 11, p. 735, 2022, https://doi.org/10.3390/educsci12110735

[18] G. W. Wright and S. Park, "The effects of flipped classrooms on K-16 students' science and math achievement: A systematic review," *Stud Sci Educ*, vol. 58, no. 1, pp. 95–136, 2022, https://doi.org/10.1080/03057267.2021.1933354

[19] F. D. Fernández-Martín, J. M. Romero-Rodríguez, G. Gómez-García, and M. R. Navas-Parejo, "Impact of the flipped classroom method in the mathematical area: A systematic review," *Mathematics*, vol. 8, no. 12, pp. 1–11, 2020, https://doi.org/10.3390/math8122162

[20] F. J. Hinojo-Lucena, Á. C. Mingorance-Estrada, J. M. Trujillo-Torres, I. Aznar-Díaz, and M. P. C. Reche, "Incidence of the flipped classroom in the physical education students' academic performance in university contexts," *Sustainability (Switzerland)*, vol. 10, no. 5, 2018, https://doi.org/10.3390/su10051334

[21] M. Gu and S. Sok, "Factors affecting the academic achievement of nursing college students in a flipped learning simulation practice," *Int J Environ Res Public Health*, vol. 18, no. 11, 2021, https://doi.org/10.3390/ijerph18115970

[22] Y. S. Moemen and I. E. T. El-Sayed, "Environmental challenges and the impact of COVID-19 on healthcare sector: The adoption of intelligent solutions," *Studies in Systems, Decision and Control*, vol. 369, pp. 41–53, 2021, https://doi.org/10.1007/978-3-030-72933-2_3

[23] T. Snoussi and A. F. Radwan, "Distance E-learning (DEL) and communication studies during covid-19 pandemic," *Utopia y Praxis Latinoamericana*, vol. 25, no. Extra10, pp. 253–270, 2020, https://doi.org/10.5281/ZENODO.4155579

[24] S. Jacques, A. Ouahabi, and Z. Kanetaki, "Post-COVID-19 education for a sustainable future: Challenges, emerging technologies and trends," *Sustainability*, vol. 15, no. 8, p. 6487, 2023, https://doi.org/10.3390/su15086487

[25] S. Jacques and T. Lequeu, "The attractiveness of reversing teaching forms – feedback on an electrical engineering course," *International Journal of Engineering Pedagogy (iJEP)*, vol. 10, no. 3, pp. 21–34, 2020, https://doi.org/10.3991/ijep.v10i3.12361

[26] G. Ros and M. T. Rodríguez Laguna, "Influence of the flipped classroom in the scientific training of pre-service teachers: Benefits in the teaching-learning process, attitudes and expectations towards science," *Revista de Investigacion Educativa*, vol. 39, no. 2, pp. 463–482, 2021, https://doi.org/10.6018/rie.434131

[27] G. Ren, P. Zhuang, X. Guan, K. Tian, and J. Zeng, "How do blended biochemistry classes influence students' academic performance and perceptions of self-cognition?," *Front Psychol*, vol. 13, 2022, https://doi.org/10.3389/fpsyg.2022.843392

[28] M. Gu and S. Sok, "Factors affecting the academic achievement of nursing college students in a flipped learning simulation practice," *Int J Environ Res Public Health*, vol. 18, no. 11, 2021, https://doi.org/10.3390/ijerph18115970

[29] P. Youhasan, Y. Chen, M. Lyndon, and M. A. Henning, "Exploring the pedagogical design features of the flipped classroom in undergraduate nursing education: A systematic review," *BMC Nurs*, vol. 20, no. 1, 2021, https://doi.org/10.1186/s12912-021-00555-w

[30] V. Fornons and R. Palau, "Flipped classroom in the teaching of mathematics: A systematic review," *Education in the Knowledge Society*, vol. 22, 2021, https://doi.org/10.14201/eks.24409

[31] K. Reynolds, L. Khorramdel, and M. von Davier, "Can students' attitudes towards mathematics and science be compared across countries? Evidence from measurement invariance modeling in TIMSS 2019," *Studies in Educational Evaluation*, vol. 74, 2022, https://doi.org/10.1016/j.stueduc.2022.101169

[32] T. E. Hunt and E. A. Maloney, "Appraisals of previous math experiences play an important role in math anxiety," *Ann N Y Acad Sci*, vol. 1515, no. 1, pp. 143–154, 2022, https://doi.org/10.1111/nyas.14805

[33] M. Sirakaya and E. K. Cakmak, "The effect of augmented reality use on achievement, misconception and course engagement," *Contemp Educ Technol*, vol. 9, no. 3, pp. 297–314, 2018, https://doi.org/10.30935/cet.444119

[34] R. Ho, "Handbook of univariate and multivariate data analysis and interpretation with SPSS," *Handbook of Univariate and Multivariate Data Analysis and Interpretation with SPSS*, pp. 1–406, 2006, https://doi.org/10.1198/000313008X332287

[35] J. Robertson, "Likert-type scales, statistical methods, and effect sizes," *Commun ACM*, vol. 55, no. 5, pp. 6–7, 2012, https://doi.org/10.1145/2160718.2160721

[36] D. L. Streiner, "Starting at the beginning: An introduction to coefficient alpha and internal consistency," *J Pers Assess*, vol. 80, no. 1, pp. 99–103, 2003, https://doi.org/10.1207/S15327752JPA8001_18
[37] A. Ghasemi and S. Zahediasl, "Normality tests for statistical analysis: A guide for non-statisticians," *Int J Endocrinol Metab*, vol. 10, no. 2, pp. 486–489, 2012, https://doi.org/10.5812/ijem.3505
[38] G. W. Corder and D. I. Foreman, "Nonparametric statistics for non-statisticians: A step-by-step approach," *Nonparametric Statistics for Non-Statisticians: A Step-by-Step Approach*, pp. 1–536, 2011, https://doi.org/10.1002/9781118165881
[39] C. Y. Hung, J. C. Y. Sun, and J. Y. Liu, "Effects of flipped classrooms integrated with MOOCs and game-based learning on the learning motivation and outcomes of students from different backgrounds," *Interactive Learning Environments*, vol. 27, no. 8, pp. 1028–1046, 2019, https://doi.org/10.1080/10494820.2018.1481103
[40] V. Fornons and R. Palau, "Flipped classroom in the teaching of mathematics: A systematic review," *Education in the Knowledge Society*, vol. 22, 2021, https://doi.org/10.14201/eks.24409
[41] H. Turra, V. Carrasco, C. González, V. Sandoval, and S. Yáñez, "Flipped classroom experiences and their impact on engineering students' attitudes towards university-level mathematics," *High Educ Pedagog*, vol. 4, no. 1, pp. 136–155, 2019, https://doi.org/10.1080/23752696.2019.1644963

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PAPER

Students' Alternative Conceptions and Teachers' Views on the Implementation of Pedagogical Strategies to Improve the Teaching of Chemical Bonding Concepts

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ABSTRACT

The concept of chemical bonding is a crucial one in chemistry that occurs throughout the school curriculum and forms the basis of many topics in chemistry. Furthermore, learning about chemical bonding allows the learner to make predictions and provide explanations regarding the physical and chemical properties of substances. However, chemical bonding has been cited as one of the most difficult chemistry concepts for many secondary and higher education students to understand, and therefore, teachers can find it difficult to teach this concept due to the complexity of the underlying theory as well as the need to use abstract models to represent chemical bonds. The teaching methods used in the implementation of the concept can also be challenging. The aim of this study is to reveal the difficulties and alternative conceptions encountered by Moroccan secondary school students when learning concepts related to chemical bonding, the main causes of these difficulties, and the strategies used by teachers to help students overcome these obstacles. In this study, we conducted a survey of 57 Moroccan secondary school physical science teachers by means of a questionnaire. The questionnaire, consisting of three parts, was used to collect the data. Each part contains closed questions, open questions, and multiple-choice questions. The analysis of the results highlights the difficulties and alternative conceptions most frequently made by the students, namely: the octet rule, the geometry of molecules, and the polarity of molecules. Factors contributing to students' misconceptions include the nature of abstract concepts, the use of models, and the difficulty for teachers to explain certain concepts related to chemical bonding. The study also presents some suggestions for improving the teaching of chemical bonding, such as integrating information and communication technologies (ICT), diversifying the teaching tools used, and taking into account students' pre-existing conceptions. This can help teachers, curriculum developers, and textbook authors make the subject easier for students and address their misconceptions.

KEYWORDS

chemistry teaching, alternative conceptions, learning difficulties, chemical bonding

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1 INTRODUCTION

Chemistry is considered a fundamental science that depends on several fields of knowledge, such as health, biology, and geology … Therefore, an understanding of the basic concepts of chemistry is necessary, including chemical bonding and associated concepts such as the octet rule, ionic bonding, and molecular geometry… .

Chemical bonding is one of the key and fundamental concepts in chemistry [1–3]. It is a fundamental concept at the heart of the basic structural interface of chemistry, a key concept in explaining the cohesion of matter and molecular architecture, and it allows for the understanding of the structure and properties of chemical compounds.

However, assimilating this concept can be difficult for several reasons. Firstly, chemical bonds are microscopic phenomena that cannot be directly observed with the naked eye. Therefore, understanding them requires the use of theoretical models such as Lewis models, VSEPR (Valence Shell Electron Pairs Repulsion) models, or molecular orbital theory. These models are often abstract and can be difficult for students to visualize. Furthermore, the concept of chemical bonding is closely related to other concepts in chemistry such as the electronic structure of atoms, the polarity of molecules, and intermolecular forces.

Understanding these concepts is crucial to understanding the nature of chemical bonding, but they can also be difficult to assimilate. Thus, other studies explain the difficulty related to these concepts through the influence of school textbooks [4], the use of traditional pedagogy, and classroom practice by teachers [5]. Overall, the assimilation of the concept of chemical bonding and related concepts may be difficult to teach in the chemistry classroom [6,7] due to the abstract nature of the theoretical models used [4], the complexity of the connected concepts, and the multiplicity of models proposed.

Currently, many studies conducted in the Moroccan context (university cycle only) and even globally at all school and university levels have shown that most pupils and students find major difficulties in learning the concept of chemical bonding and related concepts. Indeed, research conducted by [4,8–11] revealed that students encounter difficulties in learning the concepts related to chemical bonding. Many students have a low level of progress in learning chemical bonding and do not possess the adequate understanding required for post-secondary education in chemistry courses.

Understanding the concept of chemical bonding is crucial for learning chemistry. Chemical bonding is the central concept of many other basic concepts in the chemistry program, but its complexity can cause difficulties for students. In view of these difficulties, the question arises as to how to facilitate the assimilation of the concept of chemical bonding and related concepts by chemistry students by identifying the best teaching strategies and the most effective pedagogical methods to improve the learning and understanding of these key concepts.

The study of pupils' alternative conceptions from the teachers' point of view in the scientific literature is poorly developed from a didactic point of view. Consequently, this research will focus on teachers' perspectives as key players in the teaching and learning process.

In this respect, the aim of this study is to identify the major difficulties and the most frequent alternative conceptions related to the learning of the concept of chemical bonding and related concepts among secondary school students from the teachers' point of view, including the origin of these difficulties and the strategies that teachers use to remedy them.

To this end, answers to the following questions were sought in this study:

- What are the most common alternative conceptions and difficulties of secondary school students regarding the concepts of chemical bonding?
- What are the factors responsible for the misperception of concepts related to chemical bonding?
- How can teachers adapt their teaching strategies to help students with different levels of understanding assimilate the concept of chemical bonding?

2 LITERATURE REVIEW

Pupils have persistent difficulties with some basic concepts in chemistry, such as the relationship between ionic and covalent bonds, and the geometry of molecules. Misconceptions are common and persist even after several years of teaching. Therefore, research in chemistry didactics has targeted these difficulties and the alternative conceptions of pupils and university students for several decades. The aim is to understand the origin and nature of these difficulties in the study context in order to propose solutions to overcome them.

Learning difficulties in chemistry: This is related to the student's relationship to knowledge and concerns the cognitive processes deployed by the student in learning, alternative conceptions, and epistemological barriers, as well as the language and abstraction of knowledge in science [12].

Learning difficulties in chemistry can have multiple causes, including the complexity of concepts, the need to use abstract models, the presence of alternative conceptions and difficulties in reasoning … These difficulties can lead to misconceptions and deficiencies that persist throughout the school curriculum.

Alternative conceptions: A great deal of didactic research has shown that certain students' responses, which are generally described as "errors", are derived from a personal mode of reasoning and explanatory system, which presents a perfect and structured logic for them. This prompts didactic researchers to take an interest in and give major importance to what is called conception. Conceptions are students' internal representations of a concept, usually in science [13]. Some authors call them preconceptions, prescientific conceptions, misconceptions, primitive, naive, alternative, intuitive, erroneous, inappropriate, spontaneous, or unexpected conceptions. In English literature, the term misconception is preferred [14].

The alternative conceptual framework may have its origins in concepts learned in class, but about which students have drawn conclusions or developed explanations that are not consistent with scientific theory [15,16]. The identification of pupils' conceptions about a given concept, and moreover the identification of the origin of these conceptions or representations, could however prove very useful in constructing teaching sessions. Indeed, in light of these conceptions, the knowledge constructed by the pupils could sometimes turn out to be obstacles that hinder the learning of new notions. Among the alternative conceptions listed in the scientific literature, we will discuss those related to the concepts of chemical bonding and associated concepts.

Examples of alternative conceptions or misconceptions regarding chemical bonding: Research in literature has shown that students have difficulties with this concept, regardless of their learning context. Multiple sources, such as studies and textbooks, have identified various examples of misconceptions and alternative conceptions of chemical bonding. The following table (Table 1) presents common misconceptions regarding chemical bonding.

Table 1. Examples of common misconceptions regarding chemical bonding

Examples of Common Misconceptions	Relevant Sources
Think of a covalent bond as the equal sharing of electron pairs	[1, 17]
The student reduced the definition of the concept of chemical bond to the covalent bond	[9]
The concept of polarity and the geometry of molecules are challenging to comprehend	[17, 18, 20, 29]
Limit the type of bond to two: covalent and ionic	[17, 33]
Students believed ionic bonding was a sharing of electrons	[20, 22, 28, 30, 31]
Confusing intramolecular bonding with intermolecular bonding	[19, 24, 27]
Thinking that all the atoms in a molecule must obey the octet rule	[1, 10, 17, 23, 29, 33]
Confusing covalent and ionic bonds	[11, 19–21, 23–29, 32–33]

3 METHODOLOGY

3.1 Characteristics of the sample

The target respondents of this study were teachers in a single provincial directorate of the Regional Academy of Education and Training Casablanca-Settat region of Morocco, from the discipline of Physics and Chemistry, practicing in schools in urban areas. A total of 57 teachers from a total population of 70 participated in the questionnaire survey, and the participation rate is around 81%. The sample was selected in a simple random manner and comprised 46 men (81%) and 11 women (19%).

The following table (Table 2) presents the characteristics of the respondents. The first section of the table concerns the age of the respondents in the study, with the majority of respondents being between 31 and 40 years old (52.63%), 22.81% being under 30 years old, 15.79% being between 41 and 50 years old, and only 8.77% being over 51 years old.

Table 2. Characteristics of the participant (n = 57)

Attributes	Characteristics	Number	Percentage (%)
Age class	Under 30 years old	13	22.81%
	31 to 40 years old	30	52.63%
	41 to 50 years old	9	15.79%
	Over 51 years old	5	8.77%
Seniority	Less than 5 years	13	22.81%
	Between 5 and 10 years	19	33.33%
	Between 10 and 15 years	15	26.32%
	More than 15 years	10	17.54%
Level of study	Bachelor's degree	16	28.07%
	Master	31	54.38%
	Doctorate	10	17.54%
Professional training	Yes	48	84%
	No	9	16%
Specialty of study	Physics	29	51%
	Chemistry	28	49%

The second section of the table provides information on the professional experience of the teachers, where the majority of the respondents (33.33%) have been in the profession for between 5 and 10 years, followed by those with between 10 and 15 years (26.32%) and those with less than 5 years (22.81%), while teachers with more than 15 years of experience represent only 17.54% of the respondents (Table 2).

The third section of the table provides information on the educational backgrounds of the respondents. The majority have a master's degree (54.38%), followed by those with a bachelor's degree (28.07%) and those with a PhD (17.54%) (Table 2).

The fourth section of the table provides information on professional training, where the vast majority (84%) have received professional training in training centers, while a minority of teachers work directly without prior training (16%). Finally, the last section of the table provides data on the respondents' field of study. There is an almost equal distribution between physics and chemistry, with slightly more respondents having a specialty in physics (51%) (Table 2).

3.2 Measurement instrument

This research is conducted using a quantitative approach. To address the research questions, we employed an anonymous electronic questionnaire consisting of three distinct sections.

In the first part, entitled "Identification of difficulties and alternative conceptions", which aimed at identifying the different difficulties and alternative conceptions encountered by students regarding the concept of chemical bonding and related concepts from the teachers' perspective, we have included two questions: The first open-ended question collected different difficulties and alternative conceptions related to the concept of chemical bonding and related concepts and categorized them. The second question proposed a list of concepts related to chemical bonding, and we asked participants to select the concept(s) that seemed difficult to teach.

In the second part, entitled "Factors Responsible for the Misperception of Concepts", which aimed to determine the origin of the misperception of concepts related to chemical bonding, we proposed an evaluation of the factors influencing students' perception of the concepts relating to chemical bonding. This evaluation was carried out using a five-point Likert scale, ranging from "strongly agree", marked 5, to "strongly disagree", marked 1. In addition to this, we included multiple-choice questions (MCQs) to examine teacher-related factors such as the didactic tools and methods used to teach chemical bonding concepts and the methods used to diagnose difficulties and misconceptions.

In the third part, entitled "Solutions Proposed by Teachers to Remedy Difficulties and Alternative Conceptions", which aimed to collect proposals for solutions to difficulties related to the concept of chemical bonding and other associated concepts, we presented suggestions to overcome learning difficulties associated with the concept of chemical bonding and other related concepts. This assessment was carried out using a five-point Likert scale, ranging from "strongly agree" rated 5 to "strongly disagree" rated 1. In addition, we asked participants to suggest other solutions.

Ethical considerations: All respondents understood that participating in this study was voluntary, and they could decide to withdraw at any time. Furthermore, teachers were informed that their responses would only be used for a research study and that their identities would not be revealed.

Validation of the tool: The questionnaire was first checked and approved by four experts in the field of chemistry and education: two Moroccan university teachers at a public university in Morocco, a physics and chemistry inspector and an associate professor with 21 years of experience in teaching chemistry.

This validation process resulted in the rewording of various items to make them more understandable to the respondents and more scientifically accurate. The experts considered the final version of the questionnaire to be valid. Before being used as a data collection instrument, it is important to note that the questionnaire was tested with 20 participants with characteristics similar to those of the study participants.

Data analysis process: The quantitative data gathered through questionnaires were analyzed using descriptive analysis (means and standard deviations) using SPSS 25 and Microsoft Office Excel 365. Concerning the open-ended questions in the questionnaire, content analysis was employed to code the answers into a meaningful set of categories.

The respondents' responses, assessed on a five-point Likert scale, are interpreted as follows (Table 3): The class interval is calculated by subtracting the maximum score with the minimum score and then dividing them with the number of scales; therefore, the class interval in this case is 0.8.

Table 3. Data interpretation

Point Value	Mean Range	Level of Agreement
1	1.00–1.79	Strongly disagree
2	1.80–2.59	Disagree
3	2.60–3.39	Slightly agree
4	3.40–4.19	Agree
5	4.20–5.00	Strongly agree

The table below (Table 4) shows the results of the Cronbach's Alpha reliability test on the questionnaire. The results show that the items are highly correlated as the Cronbach's Alpha values are quite higher than the value of 0.700 which is often considered highly correlated [34,35].

Table 4. Reliability statistics

Part	Number of Items	Cronbach's Alpha
Factors responsible for the misperception of concepts.	13	0.938
Solutions proposed by teachers to remedy difficulties and alternative conceptions.	10	0.955

4 RESULTS

4.1 Identification of difficulties and alternative conceptions with regard to chemical bonding and related concepts

The following table (Table 5) lists the different difficulties and the most frequent alternative conceptions identified by the teachers among the students about chemical bonding and related concepts, classified into eight sub-categories.

Table 5. List of difficulties and alternative conceptions identified by teachers with regard to students' concepts of chemical bonding

Category	Difficulties and Alternative Conceptions Identified among Students
Electronic structure and the octet rule	• The distribution of electrons on the electronic shells. • Non-observance of the octet rule for an element in a molecule. • Understanding the electronic structure and the outer shell.
The valence shell and valence electrons	• Confusion between the valence shell and valence electrons.
Covalent and ionic bonding	• Difficulty in distinguishing the different types of bonds. • Confusion of two concepts: ionic compounds and molecules. • Difficulty in distinguishing between a covalent bond and an ionic.
Electronegativity and polarity of a molecule	• The determination of the polarity of a molecule and the link to polar bonding. • The polarity of this molecule is determined solely by the differences in electronegativity between its atoms, without taking into account the molecular shape. • The difficulty in understanding the concept of electronegativity. • The location of partial charges in a molecule.
Isomerism	• The concepts of isomerism. • The structural representation of molecules and the confusion with the Lewis representation. • Confusion between structural formulae and the Lewis representation.
The geometry of the molecule	• The representation of the geometry of a molecule and the difficulty of representing it in 3D space.
Cram model	• The difficulty in realizing the Cram representation, as well as the representation of the bonds in this representation.
Lewis structure	• Failure to respect the number of bonds a chemical element can make in a molecule. • The organization of atoms in the representation of molecules. • The representation of some specific molecules. • The understanding of binding and non-binding doublets.

We note that several very common conceptual difficulties are detected by the present research, according to the teachers' statement. The categories of responses include such things as electronic structure and octet rules, valence shell and valence electrons, covalent bonding and ionic bonding, electronegativity and polarity of a molecule, isomerism, geometry of the molecule, the Cram model, and Lewis structure. This list clearly shows that understanding the concept of chemical bonding involves mastering several interrelated concepts and that the difficulties encountered by students can come from different sources (Table 5).

By comparing the above misconceptions, we can confirm that the concepts are chained and well structured. Moreover, if the student fails to master such concepts, it may induce difficulties; for example, to predict the polarity of molecules, it is necessary to know the geometry of the molecules and their electronegativity.

In addition, the following table (Table 6) presents the results allowing us to identify the concept(s) that seem to be difficult to teach from the teachers' point of view, and which allows us to measure the teachers' mastery of the concepts, as well as their impact on the teaching-learning process.

Table 6. A list of concepts that seem difficult to teach

Concepts	Number of Responses	Percentage%
Molecule geometry	29	50.9
Cram representation	24	42.1
The Polarity of a molecule	22	38.6
Isomerism	20	35.1
Electronegativity	19	33.33
Ionic bonding	17	29.8
Lewis structure	11	19.3
Polarized bonding	11	19.3
Duet rule	4	7
Octet rule	4	7
Electronic structure	4	7
Covalent bond	3	5.3
Valence shell	2	3.5
Valence electrons	2	3.5

The teachers interviewed identified some concepts as being more difficult to teach than others. According to their views, the geometry of a molecule (50.9%), the Cram representation (42.1%), the polarity of a molecule (38.6%), isomerism (35.1%), electronegativity (33.33%), and ionic bonding (29.8%) are among the most difficult concepts to teach, while other concepts seem to pose less difficulty. These results affirm the complexity of chemical bonding concepts in chemistry teaching and help to identify the concepts that teachers have difficulties with, which can help to improve the way these concepts are taught and understood by students (see Table 5).

In terms of identifying difficulties and alternative conceptions of students regarding concepts related to chemical bonding, it was found that the majority of teachers (82.5%) were able to identify difficulties and misconceptions of students, while 17.5% claimed not to have identified them. It is clear from the responses that some chemistry teachers are not aware of or do not address the misconceptions held by students, which can lead to the persistence of these misconceptions. Therefore, the results highlight the importance of addressing students' misconceptions in chemistry teaching in order to remedy them and ensure a deeper understanding of the concepts.

These results are serious warnings for chemistry teaching at the level of secondary education in Morocco. Teachers will certainly be concerned to overcome the difficulties of concepts that do not seem to be mastered by their students, but first of all, it is necessary to know the factors responsible for the misperception of concepts.

4.2 Factors responsible for the misperception of concepts related to chemical bonding

The table below (Table 7) presents the results of our study on the factors that cause students' misperceptions of chemical bonding concepts, categorized according to respondents. These results have been classified into different categories according to the respondents interviewed.

Table 7. Factors responsible for the misperception of concepts related to chemical bonding

Factors	Items	Mean	Standard Deviation	Level of Agreement
Of didactic origin	The nature of abstract concepts.	3.05	1.540	slightly agree
	Concepts poorly adapted in the program: internal didactic transposition.	2.82	1.364	slightly agree
	Use of the textbook.	2.60	1.307	slightly agree
	Use of models (Lewis).	2.56	1.414	Disagree
Of pedagogical origin	The conditions of overcrowded classrooms.	3.39	1.656	slightly agree
	Absence of laboratory.	3.23	1.637	slightly agree
	Lack of teaching materials.	3.18	1.501	slightly agree
	Time spent on the chemistry program.	2.84	1.486	slightly agree
Student-related factors	Presence of representations (conceptions) among students.	3.07	1.321	slightly agree
	The influence of the language of instruction (language barrier).	3.09	1.491	slightly agree
	Pupils' orientation.	3.02	1.302	slightly agree
Teacher-related factors	Traditional teaching (absence of active pedagogies).	2.86	1.381	slightly agree
	Lack of training in science didactics.	2.72	1.278	slightly agree

The analysis of these results allowed us to distinguish four main sub-categories of factors that are responsible for this poor perception of chemical bonding concepts.

The first factor concerns difficulties of didactic origin, in which we find the nature of abstract concepts (3.05), concepts poorly adapted in the curriculum (2.82), the use of the textbook (2.60) and the use of models (2.56) (Table 7). The second factor is pedagogical in origin, such as overcrowded class conditions (3.39), lack of laboratories (3.23), lack of teaching materials (3.18) in addition to the time devoted to the chemistry program (2.84). The third factor is student-related difficulties, in which we find the presence of student conceptions (3.07), the influence of the language of instruction (3.09) and students' orientation (3.02). The last factor is teacher-related difficulties, considered less important, such as traditional teaching (2.86) and a lack of training in science didactics (2.72). All these last items have an agreement level of "slightly agree" except for the item "Use of models (Lewis)" which is in "disagree".

Other teacher-related factors: The table below (Table 8) shows the didactic tools used by teachers to teach concepts related to chemical bonding, as well as the number of respondents for each tool. The results show that the majority of teachers prefer the use of information and communication technologies (ICTs), such as animations and simulations, as well as molecular models (colored balls and rods). However, some teachers continue to use tools such as the blackboard and the textbook. It is important to note that the use of inappropriate teaching aids can cause difficulties for students.

Table 8. Didactic tools used by teachers to teach concepts related to chemical bonding

Didactic Tools	Percentage
Table	50.87%
Textbook	17.54%
Animations, simulations	66.67%
Molecular models (colored balls, rods for associating the balls)	57.94%

Table 9 presents the pedagogies used by teachers to teach the concepts related to chemical bonding. The results of the responses indicate that 49.1% of the teachers surveyed opt for a problem-solving method as a pedagogy for constructing the concept of chemical bonding and related concepts. However, 35.1% prefer the investigation method, and only 17.5% of the teachers prefer project-based pedagogy. Finally, almost a quarter of the respondents preferred to use the traditional method. These results highlight the diversity of pedagogies adopted by teachers to teach the concept of chemical bonding and related concepts. The presence of teachers using the traditional method may lead to misconceptions among students.

Table 9. Methods used by teachers when teaching concepts related to chemical bonding

Methods Used	Percentage
Problem solving	49.1%
Investigative pedagogy	35.1%
The traditional method	22.8%
Project-based teaching	17.5%

Table 10 presents the tools used to diagnose difficulties and misconceptions among students. The analysis of the results shows that the majority of respondents consider that exercises, summative assessments and written tests are the most common tools used to detect difficulties and misconceptions among students. This lack of assessment practice can lead to problems for students who fail to correct their misconceptions and misrepresentations early in the learning process. These results also suggest that teachers are not sufficiently aware of the importance of exploiting students' representations in their teaching, which may limit the deep understanding of chemical bonding and other related concepts.

Table 10. Methods of diagnosing difficulties and misconceptions

	Very Rarely	Rarely	From Time to Time	Often	Very Often
Assessments at the beginning of the session	17.54%	15.78%	31.57%	17.54%	17.54%
Assessments during the session	7.01%	24.56%	31.48%	28.07%	10.52%
Assessments at the end of the session	10.52%	26.31%	22.80%	22.80%	17.54%
Exercises	3.50%	8.77%	26.31%	21.05%	40.35%
Written tests	8.77%	12.28%	31.48%	28.07%	21.05%
Oral tests	19.29%	19.29%	24.56%	21.05%	15.78%
Direct questions	12.28%	22.80%	26.31%	21.05%	17.54%
Dialogue	15.78%	24.56%	22.80%	17.54%	19.29%

Finally, the pedagogical choices adopted by teachers, the ways in which difficulties are identified, as well as the limited use of didactic tools can all contribute to difficulties in learning the concept of chemical bonding and related concepts, to misunderstandings for many students.

4.3 Teachers' proposed solutions to difficulties and alternative conceptions

Table 11 presents the analysis of the responses concerning the solutions proposed by the teachers to cope with the difficulties and alternative conceptions encountered in teaching-learning related to the concepts of chemical bonding.

Table 11. Solutions proposed by teachers to deal with difficulties in learning the concept of chemical bonding and other related concepts

Items	Mean	Standard Deviation	Level of Agreement
1. Integrate information and communication technologies (ICT) such as simulations, animations, and flash tools.	4.05	1.355	Agree
2. Assess pre-requisites before starting the course.	3.98	1.445	Agree
3. Diversify teaching aids.	3.95	1.329	Agree
4. Provide in-service training for teachers to keep up with the latest teaching methods.	3.91	1.418	Agree
5. Encourage exchanges and communication between teachers.	3.91	1.258	Agree
6. To carry out practical work.	3.84	1.399	Agree
7. Adopt active teaching methods.	3.84	1.424	Agree
8. Improve communication with students by providing regular feedback on their progress.	3.82	1.227	Agree
9. Take into account students' pre-existing conceptions.	3.79	1.292	Agree
10. Modify teaching content to make it more accessible and understandable to students.	3.00	1.570	Slightly agree

The analysis of the results of the solutions proposed by the teachers to cope with the difficulties of learning concepts related to chemical bonding revealed that out of the 10 items proposed in the questionnaire, only 5 were considered very important by the teachers. Firstly, teachers indicated that it was necessary to integrate information and communication technologies (ICT) such as simulations, animations, and flashes (4.05). In second place, teachers stressed the importance of assessing students' prior knowledge before starting the course (3.98), then diversifying the didactic tools used (3.95), offering in-service training to teachers so that they can keep abreast of the latest teaching methods (3.91), and finally encouraging exchanges and communication between teachers (Table 11). Secondary proposals include conducting practical work (3.84), adopting active pedagogies (3.84), improving communication with students by providing regular feedback on their progress (3.82), taking into account students' pre-existing conceptions (3.79), and finally modifying the content of teaching to make it more accessible and understandable for students (3.00) (Table 11).

Other proposals suggested by respondents in an open-ended question to improve the teaching and learning of the concept of chemical bonding and other related concepts are grouped as follows (Table 12):

Table 12. Additional proposals suggested by respondents

Suggestions	Statement
At the Curriculum level	– Reword the part of the curriculum concerning chemical bonding concepts in the official instructions. – Expand the curriculum to include atoms with atomic numbers above 18. – Emphasize the use of the s, p, and d sublayers for electronic configuration rather than the K, L, M layers. – Allocate sufficient time for each concept to be taught.
In terms of Didactic tools	– Provide the necessary teaching materials to allow a concrete understanding of covalent bonding. – Use practical work and simulations to teach chemical bonding and the geometry of molecules. – Use appropriate simulations to enrich the teaching. – Make models of atoms available in the laboratory to enable a better understanding of covalent bonding. – Use the internet, multimedia room, and diagrams to facilitate teaching.
At the level of the didactic approach	– Work with a problem-based approach to correct misconceptions. – Encourage the investigative approach to enable students to search for the answer and information in order to avoid misconceptions. – Encourage student participation to carry out class projects related to the concept of chemical bonding.
Other suggestions	– Teach chemistry as a subject independent of physics, by chemistry specialists. – Reducing class size would allow better follow-up of students in difficulty. – Increasing the number of hours to allow more practical work to be done. – Accompanying students in difficulty. – Encourage dialogue to correct alternative conceptions.

5 DISCUSSION

Firstly, it should be recalled that the aim of this study is to explore the difficulties encountered by secondary school students in Morocco during the learning of concepts related to chemical bonding, as well as the origin of these difficulties and the strategies that teachers use to remedy them.

The results of the study highlighted the presence of difficulties and alternative conceptions among students concerning concepts related to chemical bonding. These difficulties, as perceived by teachers, can be attributed to a variety of factors such as didactic, pedagogical, and student-related factors. In addition, teachers themselves may contribute to the difficulties experienced by students. To address these learning challenges, effective strategies such as the use of information and communication technologies, the diversification of teaching tools, and the incorporation of molecular models should be included.

Concepts related to chemical bonding are key and fundamental concepts in chemistry education, indispensable for the understanding of almost all topics in chemistry [1,11]. Indeed, understanding the fundamental ideas of chemical bonding is essential for learning many concepts in chemistry, both at the secondary and higher education levels. However, these concepts are often regarded as abstract and remote from students' everyday experiences, which can lead to the emergence of alternative, erroneous conceptions, and misconceptions [8,18–19]. As a result, most students experience difficulties understanding chemical bonding and present various misconceptions about it [1,17,20–21].

The results of the study highlighted the presence of difficulties and alternative conceptions among students with regard to concepts related to chemical bonding. Teachers reported that many students had difficulties understanding the distribution of electrons on electron layers and the application of the octet rule, which is consistent with the findings of [22]. The study by Peterson et al. (1986) [23] also revealed that misconceptions about elemental stability and the octet rule are due to students' misinterpretations of these rules. In addition, students often confuse the valence layer with valence electrons, which has been reported in other studies such as those by [10,20,24].

In addition, students have difficulty distinguishing between a covalent bond and an ionic bond, as well as between ionic compounds and molecules. This is consistent with the findings [25]. In a study, Tan & Treagust (1999) [18] found that the majority of students (80.4%) thought that sodium chloride existed as molecules, suggesting that a high percentage of students do not understand the difference between the different bonds. These results are also consistent with other previous work, such as [1,6,17,19–22,26–28]. Nicoll [20] also investigated students' misconceptions about chemical bonding and revealed that students thought that ionic bonding was electron sharing, and this misconception is consistent with the findings of [29,30].

The results of the study indicated that the majority of students have misconceptions regarding the electronegativity and polarity of molecules. In particular, they have difficulty understanding the link between polar bonding and the polarity of a molecule. These results are in agreement with previous works such as those conducted [17,22,26,32]. In addition, some students find it difficult to associate the concept of polarity with electronegativity, as also found by [21,33]. Burrows and Mooring [36] stated that most students encounter difficulties in making meaningful associations between electronegativity and polar covalent bonding. Students also tend to think that the polarity of a molecule is determined solely by the differences in electronegativity between its atoms, without taking into account the molecular shape. These findings have also been supported by previous studies. With regard to the geometry of molecules, students have difficulties grasping the spatial representation of molecules and identifying their shape. These results are consistent with those of [20,28].

It is important to understand and identify the factors responsible for the misperception of concepts related to chemical bonding that often lead students to develop misconceptions. Several factors can explain this misunderstanding of these concepts, according to the teachers' views, including didactic factors, such as the abstract nature of the concepts, which appears to be a major obstacle. These results are consistent with previous studies conducted by [1,6,19]. Thus, the use of pedagogical models in chemistry teaching [1] and textbooks used by students may also be an explanatory factor [37,38].

On the other hand, there are other pedagogical factors, such as overcrowded classroom conditions, a lack of laboratory facilities, a lack of teaching materials, the amount of time devoted to the chemistry curriculum and other student-related factors, such as the presence of alternative representations or conceptions, the influence of the language of instruction as a linguistic barrier [39], and student orientation. It is therefore important to take these different factors into account in order to improve the teaching and understanding of concepts related to chemical bonding.

Our survey also reflects the fact that teachers can also be a source of difficulties for students. Their teaching style and use of traditional or simplistic pedagogical approaches are often ineffective in helping students fully understand abstract concepts [1,8]. Furthermore, the limited and insufficient use of didactic tools is not sufficient to improve students' understanding. This finding is supported by the results of previous research conducted by [40], as well as the lack of training in science didactics. This result can be explained by the presence of teachers in the sample who directly perform the work without prior professional training.

Most of the teachers interviewed do not value assessment and its roles in the training of students, such as diagnostic assessment to check prerequisites and formative assessment to monitor students' achievements. Over time, these assessment practices should be used with the aim of correcting misconceptions [1,41]. In addition, the study showed that teachers also face difficulties in teaching some basic concepts related to chemical bonding, which can lead to misconceptions among students. Indeed, the misconceptions that appear in teachers are also found in students [42].

It is recognized that students who do not master concepts related to chemical bonding during their high school years may struggle to understand them at a more advanced level [1,20,36]. Teachers therefore need to be aware of these difficulties among students.

Teachers have proposed effective strategies to address their students' alternative conceptions and learning difficulties. Firstly, the integration of information and communication technologies (ICT) such as simulations and animations can improve the quality of chemical bonding related educational content and help students overcome learning difficulties [37,43–47].

It is also recommended to assess the students' pre-knowledge before starting the course and to diversify the didactic tools [48]. including using molecular models for a better understanding of chemical bonding, according to [37,49]. Furthermore, teaching chemistry with active pedagogies is recommended, as stated by researchers [1,8,49], in order to avoid misconceptions. For this reason, teachers suggest in-service training to keep themselves updated with the latest teaching methods.

Reforms may be needed in the chemistry curriculum to facilitate the understanding of concepts related to chemical bonding at all levels. Our findings can be contextualized in the study; for example, according to [8] the best sequence for teaching bonding is to follow the following order: covalent bond, polar covalent bond, and ionic bond. Nicoll [20] suggests that teachers should emphasize transitions between the symbolic, the macroscopic, and the microscopic [11] through the adoption of a spiral curriculum covering the three years of upper secondary education.

Other results depend on the context of the study, such as reducing class size for better follow-up of struggling students, increasing the time allocated to practical work, teaching chemistry by chemistry specialists independently of physics, and supporting struggling students to cope with problems related to the teaching and learning of chemical bonding concepts.

Having considered all this information, it is crucial to create learning environments that incorporate appropriate pedagogical strategies and conceptual change techniques in order to address misconceptions and alternative conceptions related to the teaching and learning of the chemical bonding concept.

The study has some limitations that need to be mentioned. First of all, it is based only on teachers' opinions. Furthermore, it focuses only on teachers working in public schools. Finally, as the sample studied was very limited, consisting of only 57 teachers, it is clear that further research is needed to confirm the results and determine how teachers' practices regarding concepts related to chemical bonding impact students' understanding.

6 CONCLUSION AND PERSPECTIVES

From the results of our study, it appears that Moroccan students have difficulties assimilating the concept of chemical bonding and related concepts. These difficulties, as well as alternative conceptions, stem from several didactic, pedagogical, and student-related factors. Our results also highlight the fact that teachers can be a source of these difficulties, both in terms of the pedagogical methods used and assessment practices that do not sufficiently take modern assessment strategies into account, as well as the limited use of didactic tools. These results corroborate the findings of the existing literature on students' conceptions of chemical bonding.

Teachers should use computer simulations, animations, and molecular models to help students master the abstract concept of chemical bonding. In addition, learning environments based on active pedagogies, the use of appropriate teaching materials, and effective assessment strategies should be designed to address students' misconceptions about chemical bonding. It is recommended that in-depth studies be conducted by chemistry researchers to evaluate the effectiveness of these strategies.

In conclusion, it should be emphasized that multiple strategies are available to improve students' understanding of chemical bonding. In this context, teachers should be aware of the most common misconceptions and their levels, so that they can manage and apply new approaches in their teaching.

7 REFERENCES

[1] T. Levy Nahum, R. Mamlok-Naaman, A. Hofstein, and K. S. Taber, "Teaching and learning the concept of chemical bonding," Stud. Sci. Educ., vol. 46, no. 2, pp. 179–207, 2010. https://doi.org/10.1080/03057267.2010.504548

[2] T. Holme, C. Luxford, and K. Murphy, "Updating the general chemistry anchoring concepts content map," J. Chem. Educ., vol. 92, no. 6, pp. 1115–1116, 2015. https://doi.org/10.1021/ed500712k

[3] K. V. F. Fatokun, "Instructional misconceptions of prospective chemistry teachers in chemical bonding," Int. J. Sci. Technol. Educ. Res., vol. 7, no. 2, pp. 18–24, 2016. https://doi.org/10.5897/IJSTER2016.0357

[4] A. Bergqvist and S.-N. Chang Rundgren, "The influence of textbooks on teachers' knowledge of chemical bonding representations relative to students' difficulties understanding," Res. Sci. Technol. Educ., vol. 35, no. 2, pp. 215–237, 2017. https://doi.org/10.1080/02635143.2017.1295934

[5] J. Wiener, "Science teachers' conceptions of atomic models," European Journal of Mathematics and Science Education, vol. 1, no. 2, pp. 67–80, 2020. https://doi.org/10.12973/ejmse.1.2.67

[6] J. Joki and M. Aksela, "The challenges of learning and teaching chemical bonding at different school levels using electrostatic interactions instead of the octet rule as a teaching model," Chem. Educ. Res. Pr., vol. 19, no. 3, pp. 932–953, 2018. https://doi.org/10.1039/C8RP00110C

[7] M. Meltafina, W. Wiji, and S. Mulyani, "Misconceptions and threshold concepts in chemical bonding," J. Phys. Conf. Ser., vol. 1157, p. 042030, 2019. https://doi.org/10.1088/1742-6596/1157/4/042030

[8] H. S. Dhindsa and D. F. Treagust, "Prospective pedagogy for teaching chemical bonding for smart and sustainable learning," Chem. Educ. Res. Pr., vol. 15, no. 4, pp. 435–446, 2014. https://doi.org/10.1039/C4RP00059E

[9] A. Bouayad, F. Kaddari, M. Lachkar, and A. Elachqar, "Conceptions of the first-year license students on the concept 'chemical bond,'" J. Mod. Educ. Rev., vol. 5, no. 7, pp. 686–693, 2015. https://doi.org/10.15341/jmer(2155-7993)/07.05.2015/006

[10] E. Erman, "Factors contributing to students' misconceptions in learning covalent bonds: Factors contributing to students' misconceptions," J. Res. Sci. Teach., vol. 54, no. 4, pp. 520–537, 2017. https://doi.org/10.1002/tea.21375

[11] G. Tsaparlis, E. T. Pappa, and B. Byers, "Proposed pedagogies for teaching and learning chemical bonding in secondary education," Chem. Teach. Int., vol. 0, 2019. https://doi.org/10.1515/cti-2019-0002

[12] A. H. Simone, "Impact d'une formation collaborative donnée à des enseignants de chimie du secondaire sur l'enseignement et l'apprentissage du concept de mole," doctoral thesis, University of Montreal, 2019.

[13] D. F. Treagust and R. Duit, "Conceptual change: A discussion of theoretical, methodological and practical challenges for science education," Cult. Stud. Sci. Educ., vol. 3, no. 2, pp. 297–328, 2008. https://doi.org/10.1007/s11422-008-9090-4

[14] J. Nussbaum and S. Novick, "Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy," Instr. Sci., vol. 11, no. 3, pp. 183–200, 1982. https://doi.org/10.1007/BF00414279

[15] C. Cormier, "Étude des conceptions alternatives et des processus de raisonnement des étudiants de chimie du niveau collégial sur la molécule, la polarité et les phénomènes macroscopiques," doctoral thesis, University of Montreal, 2014.

[16] I. Kaniawati, "Implementation of Interactive Conceptual Instruction (ICI) Learning Model Assisted by Computer Simulation: Impact of Students' Conceptual Changes on Force and Vibration," Int. J. Emerg. Technol. Learn., vol. 16, no. 22, pp. 167–188, 2021. https://doi.org/10.3991/ijet.v16i22.25465

[17] H. Özmen, "Some student misconceptions in chemistry: A literature review of chemical bonding," J. Sci. Educ. Technol., vol. 13, no. 2, pp. 147–159, 2004. https://doi.org/10.1023/B:JOST.0000031255.92943.6d

[18] D. K. C. Tan and D. F. Treagust, "Evaluating students' understanding of chemical bonding. School Science Review," vol. 81, no. 294, pp. 75–84, 1999.

[19] R. Vladušić, R. B. Bucat, and M. Ožić, "Understanding ionic bonding – a scan across the Croatian education system," Chem. Educ. Res. Pr., vol. 17, no. 4, pp. 685–699, 2016. https://doi.org/10.1039/C6RP00040A

[20] G. Nicoll, "A report of undergraduates' bonding misconceptions," Int. J. Sci. Educ., vol. 23, no. 7, pp. 707–730, 2001. https://doi.org/10.1080/09500690010025012

[21] P. Kumpha, P. Suwannoi, and D. F. Treagust, "Thai grade 10 students conceptual understanding of chemical bonding," Procedia Soc. Behav. Sci., vol. 143, pp. 657–662, 2014. https://doi.org/10.1016/j.sbspro.2014.07.458

[22] R. K. Coll and D. F. Treagust, "Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding," J. Res. Sci. Teach., vol. 40, no. 5, pp. 464–486, 2003. https://doi.org/10.1002/tea.10085

[23] R. Peterson, D. Treagust, and P. Garnett, "Identification of secondary students' misconceptions of covalent bonding and structure concepts using a diagnostic instrument," Res. Sci. Educ., vol. 16, no. 1, pp. 40–48, 1986. https://doi.org/10.1007/BF02356816

[24] K. S. Taber, "An alternative conceptual framework from chemistry education," Int. J. Sci. Educ., vol. 20, no. 5, pp. 597–608, 1998. https://doi.org/10.1080/0950069980200507

[25] H. K. Boo, "Students' understandings of chemical bonds and the energetics of chemical reactions," J. Res. Sci. Teach., vol. 35, no. 5, pp. 569–581, 1998. https://doi.org/10.1002/(SICI)1098-2736(199805)35:5<569::AID-TEA6>3.0.CO;2-N

[26] S. Ünal, B. Coştu, and A. Ayas, "Secondary school students' misconceptions of covalent bonding, " J. Turk. Sci. Educ., vol. 7, no. 2, pp. 3–29, 2010.

[27] M. Vrabec and M. Prokša, "Identifying misconceptions related to chemical bonding concepts in the Slovak school system using the bonding representations inventory as a diagnostic tool," J. Chem. Educ., vol. 93, no. 8, pp. 1364–1370, 2016. https://doi.org/10.1021/acs.jchemed.5b00953

[28] G. Tsaparlis, E. T. Pappa, and B. Byers, "Teaching and learning chemical bonding: Research-based evidence for misconceptions and conceptual difficulties experienced by students in upper secondary schools and the effect of an enriched text," Chem. Educ. Res. Pr., 2018. https://doi.org/10.1039/C8RP00035B

[29] R. K. Coll and N. Taylor, "Alternative conceptions of chemical bonding held by upper secondary and tertiary students," Res. Sci. Technol. Educ., vol. 19, no. 2, pp. 171–191, 2001. https://doi.org/10.1080/02635140120057713

[30] C. J. Luxford and S. L. Bretz, "Development of the bonding representations inventory to identify student misconceptions about covalent and ionic bonding representations," J. Chem. Educ., vol. 91, no. 3, pp. 312–320, 2014. https://doi.org/10.1021/ed400700q

[31] S. Ünal, M. Çalık, A. Ayas, and R. K. Coll, "A review of chemical bonding studies: Needs, aims, methods of exploring students' conceptions, general knowledge claims and students' alternative conceptions," Res. Sci. Technol. Educ., vol. 24, no. 2, pp. 141–172, 2006. https://doi.org/10.1080/02635140600811536

[32] K. Taber, "Constructivism as Educational Theory: Contingency in Learning, and Optimally guided Instruction," Nova Science Publishers Inc., pp. 39–61, 2011.

[33] K. Danckwardt-Lillieström, M. Andrée, and M. Enghag, "The drama of chemistry – supporting student explorations of electronegativity and chemical bonding through creative drama in upper secondary school," Int. J. Sci. Educ., vol. 42, no. 11, pp. 1862–1894, 2020. https://doi.org/10.1080/09500693.2020.1792578

[34] J. Pallant, "SPSS Survival Manual: A step by step guide to data analysis using IBM SPSS," (7e éd.), Routledge, 2020. https://doi.org/10.4324/9781003117452

[35] J. W. Creswell and D. J. Creswell, "Research design: Qualitative, quantitative, and mixed methods approaches," (5e éd.), SAGE Publications, Inc, 2018.

[36] N. L. Burrows and S. R. Mooring, "Using concept mapping to uncover students' knowledge structures of chemical bonding concepts," Chem. Educ. Res. Pr., vol. 16, no. 1, pp. 53–66, 2015. https://doi.org/10.1039/C4RP00180J

[37] M. I. Stojanovska, B. T. Soptrajanov, and V. M. Petrusevski, "Addressing misconceptions about the particulate nature of matter among secondary-school and high-school students in the Republic of Macedonia," Creat. Educ., vol. 03, no. 05, pp. 619–631, 2012. https://doi.org/10.4236/ce.2012.35091

[38] A. Bergqvist, M. Drechsler, O. De Jong, and S.-N. C. Rundgren, "Representations of chemical bonding models in school textbooks – help or hindrance for understanding?" Chem. Educ. Res. Pr., vol. 14, no. 4, pp. 589–606, 2013. https://doi.org/10.1039/C3RP20159G

[39] M. Jarmouni, "L'apprentissage de la physique-chimie en première année d'université au Maroc : entre difficultés et solutions," Revue Marocaine de l'Évaluation et de la Recherche en Éducation, N°6. 2021.

[40] G. Tsaparlis and E. T. Pappa, "Types of intra-and intermolecular bonding: The case of general chemistry textbooks," Proceedings of the ESERA 2011 Conference, Lyon, France, 2012.

[41] C. Srour, A. Atibi, K. El Kababi, and M. Radid, "Assessment of learning and its practices in the secondary school through reforms of the Moroccan education system," Test Engineering and Management, vol. 7, no. 7, pp. 8654–8664, 2020.

[42] N. Palisoa, D. Tahya, and V. Kayadoe, "Students misconception identification of chemical candidates teachers using three tier test method in the basic concept of chemical bond," Edu Sciences, vol. 1, no. 1, pp. 37–43, 2020. https://doi.org/10.30598/edusciencesvol1iss1pp37-43

[43] H. Özmen, H. Demircioğlu, and G. Demircioğlu, "The effects of conceptual change texts accompanied with animations on overcoming 11th-grade students' alternative conceptions of chemical bonding," Comput. Educ., vol. 52, no. 3, pp. 681–695, 2009. https://doi.org/10.1016/j.compedu.2008.11.017

[44] M. Agarwal and S. Saha, "Learning chemistry through puzzle-based game: Atoms to Molecule," 9th International Conference on Emerging eLearning Technologies and Applications (ICETA), 2011. https://doi.org/10.1109/ICETA.2011.6112613

[45] I. Kaniawati, "An analysis of students' misconceptions on the implementation of active learning of optics and photonics approach assisted by computer simulation", Int. J. Emerg. Technol. Learn., vol. 15, no. 09, pp. 76–93, 2020. https://doi.org/10.3991/ijet.v15i09.12217

[46] K. Moundy, N. Chafiq, and M. Talbi, "Digital textbook and flipped classroom: Experimentation of the self-learning method based on the development of soft skills and disciplinary knowledge", Int. J. Emerg. Technol. Learn., vol. 17, no. 07, pp. 240–259, 2022. https://doi.org/10.3991/ijet.v17i07.28933

[47] A. Lahlali, N. Chafiq, M. Radid, and K. Moundy, "Teachers' attitudes towards integrating ICT in teaching chemistry in Morocco: Contribution, constraints and perspectives," Journal of Hunan University (Natural Sciences), vol. 59, no. 2, pp. 215–226, 2023. https://doi.org/10.55463/issn.1674-2974.50.2.23

[48] H. A. Marifa, M. A. Abukari, J. A. Samari, P. Dorsah, and F. Abudu, "Chemistry teachers' pedagogical content knowledge in teaching hybridization," Pedagog. Res., vol. 8, no. 3, p. em0162, 2023. https://doi.org/10.29333/pr/13168

[49] R. Kozma and J. Russell, "Students becoming chemists: Developing representational competence," in Visualization in Science Education, Dordrecht: Springer Netherlands, pp. 121–145, 2005. https://doi.org/10.1007/1-4020-3613-2_8

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PAPER

The Nature of Project Management Found in Nature: Comparative Study at High Education Institutions

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ABSTRACT

This research's urgency is evident from the growing gap between students' expectations and what universities are able or willing to provide. The theoretical background is based on constructivist learning theories and a praxiological approach. The parallel group method laid the basis of this study design when comparing project management students from two universities, A and B. In addition, a specific pedagogical experiment in the forest was implemented at University A. The experiment lasted one academic year and included a total of 179 students. Work breakdown structure, the Critical Path Method, resource management, planning, manipulative business practices, and the role of team members were demonstrated in parallel with bees, ants, bumblebees, wolves, zombie mushrooms, squirrels and orangutans. Experimental intervention at University A has led to higher point scores on achievement tests compared to University B students and brought other remarkable findings, "aha" moments and answers to the assigned research questions: What key moments increase student engagement during the class (1), and what are the findings and recommendations for future project management pedagogy (2). This study combines quantitative and qualitative methods, including bio-mimicry analogies, parallel group technique, focus groups, action- and game-based learning, achievement test, and statistical tests.

KEYWORDS

project ecosystem, forest ecosystem, biomimicry, achievement test, focus groups, game-based learning

1 INTRODUCTION

The complexity of today's world requires project managers who can demonstrate depth and creativity of mindset. The new keys to efficiency and prosperity are novel ideas, emotional intelligence, critical thinking, visionary behaviour, the use of personal strengths of project team members and insight [1]–[4]. When looking for a solution to any problem, we can find inspiration in how systems work in nature [5]; patterns are everywhere in the great outdoors and can be observed in structures,

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events, and interrelationships [6]–[7]. Nature is 3.8 billion years ahead of humans, so it would be wise to use this massive stock of "research and development" [8]–[9], such as obtaining and using resources (essential for the project), processing information and reproducing it. Biomimetics (biomimicry) studies living organisms, their structures and composition to imitate their properties and use them to develop new technologies or solutions to current problems [10]. Biomimetics is the application of lessons from nature to people, societies, and organisations, even applicable to project management—while encouraging students to be positive agents of change in the world [11]–[14].

However, the actual situation in the education sector is far from this idea. At most universities, project management is regarded as a subdiscipline and trans-functional discipline at the same time [15]. Organisations, universities, students and professional bodies consider project management as a set of methods, techniques and tools interacting with other fields to bring something new [16]–[18]. This situation responds to the positivist paradigm. Geist and Myers [19] recommend combining hands-on activities with theoretical approaches to project management pedagogy.

Teaching and learning have been identified as significant issues in the debates on the re-evaluation of project management, which is supposed to consist of changes in the conceptualisation of management, a focus on soft skills and the acceptance of the fact that a "one-fits-all" approach is not viable [20]–[22]. Other reasons for the transformation of educational activities are today's "shrewd, knowledgeable and media-savvy" students who have different expectations from higher education than they currently receive. This fact calls for a change in the student-teacher relationship within higher education [23]. Educators need to become coaches and facilitators of learning [24]. Such changes, however, encourage students to extract meaning from interpreting information rather than being passive recipients [25]–[28]. All these challenges led to these research questions:

RQ1: Do forest parallels contribute to increased student engagement and better outcomes?

RQ2: What are the findings and recommendations for future project management pedagogy?

1.1 Research design considerations

Two primary influences shaped the study design: constructivist theories of learning [29]–[32] and a praxiological approach [33]. Teacher-as-researcher implemented an extraordinary pedagogical experiment in the forest to connect learning and practice into one unit. Green spaces of nature provide a neutral ground for shared activities [34]. Environments rich in biodiversity directly affect the outcomes of people engaged in these activities [35]–[41]. The experiment aimed to increase students' engagement and improve their educational results. The following hypotheses were determined.

H0: No difference in point scores between UnivA and UnivB groups will exist.

Ha: Issues explained on forest ecosystem will lead to higher point scores in the achievement test compared to the control group at UnivB.

This study combines quantitative and qualitative methods (bio-mimicry analogies, Focus Groups, parallel groups, and statistical tests).

2 MATERIALS AND METHODS

This empirical research is based on systematic cognitive activity, data collection techniques, and observation of events and processes, followed by processing and interpreting their results. The teacher-as-researcher is also the primary instrument for data collection and analysis. The driving force of the praxeological approach is the experiment, which is carried out to verify the initial assumption's validity. In the pedagogical experiment, at least two parallel groups of students with similar compositions are assumed, and the effect of the intervention is evaluated [42]–[45]. The "parallel groups" method [46]–[47] was used when comparing two groups. This technique achieves more reliable results (compared to the method of one group). The data was collected from September 2021 – June 2022. For one academic year, the teacher-as-researcher focused on working with two selected groups of students at *UnivA* and *UnivB*. Learning objectives and competencies were almost identical.

A project manager-practitioner was also engaged at higher education institutions and supplemented the teacher's explanation with examples of good practices. Standard evaluation and summative assessment were practised at the *UnivB*, where the experiment was not carried out. Instead, the experiment was realised at *UnivA* and was based on action- and game-based learning [48]–[54]. Some project management issues (topics) taught at *UnivA* were moved to the forest environment, where the teacher-as-researcher demonstrated Work Breakdown Structure (WBS), the Critical Path Method, resource management, manipulative practices, and the role of team members in the examples of wild animals. Students worked in five-people teams [55], searching for similarities between humans and wild animals through observation, action- and game-based learning, brainstorming, and mind maps.

The effectiveness of both teaching methods is represented by the knowledge achieved by the students at the end of the experiment, measured by the achievement test [56]–[58]. A criterion-referenced summative achievement test was chosen with broad open tasks requiring a more extensive answer, which are suitable for solving problem situations. The results are shown in Table 1 – Student Performance. When evaluating the responses, weighted scoring was used, assigning different points to the tasks according to their difficulty. The minimum success rate was 60%.

The evaluation of the results differed due to the number of points allocated to individual questions. Twenty was the maximum number of points that could be obtained for each question, with the minimum being four. In the evaluation in the results section, the given range of possible points is then awarded for each question. The character of the assessment corresponded to the ordinal scale [59]. Kolmogorov-Smirnov, Shapiro-Wilk, and Mann-Whitney U tests were used for preliminary data set testing to find possible parametric distribution [60]–[62]. Due to the dual character of the data, it is presented as the median with lower and upper quartiles and the mean ± standard deviation in the descriptive statistics. If students refused to answer the question, this answer was counted as a missing value (not substituted by zero) [63]–[65].

A moderated discussion (Focus Group) was also chosen to explore the participants' attitudes and opinions. The output is usually information that would not appear in the questionnaire; thus, a deeper understanding of the problem is mediated. In addition, group atmosphere can reduce certain stereotypes and attitudinal patterns and help reveal hidden and subsurface connections that would not be noticed in other types of research [66]–[67]. The experimental group participants were asked the following questions:

- *Which analogy between the project and forest ecosystem do you find most compelling and applicable to the project's teamwork?*
- *Which parallel with the forest ecosystem impressed the most and why?*
- *What animal behaviour is closest to human expression?*

2.1 Selected chapters demonstrated the analogy of project ecosystem – forest ecosystem

The *Work Breakdown Structure* was explained using the example of a beehive. A hierarchical work breakdown structure connects the WBS and the beehive.

Completed projects also require creativity and the use of teamwork strengths. A *project team* is a group assembled for a certain period to achieve a project goal within a set deadline. The team has precisely defined powers and a fixed financial budget. Team members may have different professions and may only meet for the first time at the start of the project, yet they must work together as one body. Team members must be able to communicate and cooperate effectively with each other, which was demonstrated in the analogy of a wolf pack. A pack of wolves includes individuals of various ages and is led by an alpha pair. The pack has strict social rules, which the alpha pair strictly requires of all members. The alpha male ensures tasks and lineage. Beta males are assigned the protection of the pack, which is why these individuals are the strongest and in the best condition. Wolves in a hierarchical position among these individuals are in charge of hunting and caring for the young. The wolf pack is an example of a collaborative, participative or transformational leadership model.

Ants and ground bumblebees (*Bombus terrestris*) discovered the algorithm for finding the Critical Path, which can plan their journey in such a way as to cover as few kilometres as possible [68]–[69]. *Resource management* was introduced to students on fox squirrels (*Sciurus niger*), which have a system for sorting and gathering supplies for the winter; some of them sort nuts according to species, quality and personal taste preferences.

Planning is the dominant yet least popular activity of project managers. To motivate course participants, the behaviour of orangutans was introduced. Orangutans announce their travel plans the night before by calling in the direction of their intended journey.

The course participants were introduced to the alien fungus *Ophiocordyceps unilateralis* attacking ants *Camponotus*. The spores of the fungus invade the ant through the cuticle, enter the nervous system and begin to produce a chemical that controls the ant; its internal organs are converted to sugar so that the fungus can grow better. The ant becomes a puppet, the fungus a manipulator—a pattern of *parasitic and manipulative business practices*.

3 RESULTS

This section presents the similarities found between the project and the forest ecosystem in Tables 1–3 with the student's performance, including achievement tests' evaluation (median, standard deviation, z-value, and p-value). Achievement tests contain 11 questions, which differ from each other in the number of points according to their level of difficulty. This section also includes selected statements from Focus Group participants.

Table 1. Student performance C (*UnivB*) group (n = 92)

Question No	PM Task	Range	C (UnivB) Group (n = 92)	
			Median (Q1; Q3)	Mean ± Sd
1	WBS (bee hive, anthill)	10 points	6.00 (4.00; 8.00)	7.13 ± 3.42
2	Planning (orangutan)	10 points	6.00 (4.00; 8.00)	5.45 ± 3.83
3	Critical Path Method (ants, bumblebee)	20 points	14.00 (12.00; 16.00)	13.58 ± 4.10
4	Financing (textbook)	10 points	8.50 (4.50; 6.50)	5.45 ± 2.15
5	Project resources (Fox squirrel)	10 points	7.00 (4.00; 6.00)	6.50 ± 4.12
6	Risks (textbook)	10 points	8.00 (2.00; 8.00)	4.82 ± 2.53
7	Changes in projects (textbook)	6 points	2.00 (2.00; 4.00)	2.87 ± 1.23
8	Control methods (textbook)	10 points	6.50 (4.50; 6.00)	4.31 ± 3.28
9	Quality (textbook)	10 points	8.50 (6.50; 4.50)	7.58 ± 2.06
10	Unfair practices (zombie mushroom)	10 points	6.50 (4.50; 6.00)	5.45 ± 3.17
11	Project team (wolfpack)	6 points	4.50 (2.00; 8.00)	3.92 ± 2.83

Table 2. Student performance E (*UnivA*) group (n = 87)

Question No	PM Task	Range	E (UnivA) Group (n = 87)	
			Median (Q1; Q3)	Median (Q1; Q3)
1	WBS (bee hive, anthill)	10 points	8.00 (7.00; 9.00)	8.00 (7.00; 9.00)
2	Planning (orangutan)	10 points	7.50 (4.00; 8.00)	7.50 (4.00; 8.00)
3	Critical Path Method (ants, bumblebee)	20 points	18.00 (18.50; 16.50)	18.00 (18.50; 16.50)
4	Financing (textbook)	10 points	6.50 (6.00; 10.00)	6.50 (6.00; 10.00)
5	Project resources (Fox squirrel)	10 points	8.50 (6.00; 8.00)	8.50 (6.00; 8.00)
6	Risks (textbook)	10 points	8.00 (4.00; 8.00)	8.00 (4.00; 8.00)
7	Changes in projects (textbook)	6 points	4.00 (2.00; 5.00)	4.00 (2.00; 5.00)
8	Control methods (textbook)	10 points	6.50 (8.00; 10.00)	6.50 (8.00; 10.00)
9	Quality (textbook)	10 points	7.50 (6.50; 8.00)	7.50 (6.50; 8.00)
10	Unfair practices (zombie mushroom)	10 points	8.50 (6.50; 10.00)	8.50 (6.50; 10.00)
11	Project team (wolfpack)	6 points	5.50 (4.00; 8.00)	5.50 (4.00; 8.00)

Table 3. Mann-Whitney U test

Question No	PM Task	Range	Mann-Whitney U Test	
			Z Value	p-Value
1	WBS (bee hive, anthill)	10 points	–3.76	<0.01*
2	Planning (orangutan)	10 points	–12.87	<0.01*
3	Critical Path Method (ants, bumblebee)	20 points	–7.18	<0.01*
4	Financing (textbook)	10 points	11.64	<0.01*
5	Project resources (Fox squirrel)	10 points	–6.25	<0.01*
6	Risks (textbook)	10 points	–2.25	0.25
7	Changes in projects (textbook)	6 points	–6.35	<0.01*
8	Control methods (textbook)	10 points	–8.36	0.06*
9	Quality (textbook)	10 points	13.05	<0.01*
10	Unfair practices (zombie mushroom)	10 points	–6.12	<0.01*
11	Project team (wolfpack)	6 points	–3.89	<0.01*

Higher values equal a better result. No differences between groups were found for questions (7) and (9), i.e., risk management methods ($p = 0.25$) and control methods such as Milestones Trend Analysis, Structure Status Deviation, and Earned Value Management ($p = 0.06$). Questions No. (4) and (10) dealing with project financing and quality management have positive z-value = 11.64 and z-value = 13.05, which indicates that in these questions, the experimental group from *UnivA* was significantly worse compared to the control group from *UnivB.*

These phenomena may occur because these four topics were explained and presented to the students from a textbook, not by comparison with wild forest animals. Therefore, the teacher-as-researcher did not find suitable parallels or analogies for the abovementioned issues. Another reason could be that the experimental group (*UnivA*) had already adopted fieldwork in nature and could perceive the return to the classic textbook negatively. On the contrary, nothing changed for the control group (*UnivB*).

Project management is not only about using methods and techniques, but it is a specific philosophy and style of work, representing a particular way of thinking.

It is a remarkable characteristic of humans to quickly understand new unknown facts using analogies (similarities, parallels) with another already known situation [22]. The analogy is a heuristic method of cognition based on structural isomorphism [23], [29]. At the beginning of an analogous situation, there is the nescience of something, which is to be overcome, clarified and enlightened by the previously known content. The effects achieved by this method are enhanced by the synergistic effect of teamwork (on which project management is based) [24]. The backbone of project management is the time-resource analysis of the project based on the Network Diagram, so it is necessary to know the algorithms and logic of its construction. The Critical Path is derived from the Network Diagram and is difficult for students to understand. For simplicity, an analogy between bumblebees and ants was used. The bumblebee does not fly across the meadow along the randomly chosen route. Every day, bumblebees solve a task that mathematicians call the "traveller's problem"; they must plan their journey to visit all the cities while covering as few kilometres as possible [68]. The secret of ants' sense of direction lies in counting steps and remembering successive turns [69]. The WBS aims to break down the project into detailed activities so that responsibilities, effort, and time horizons can be assigned to them [2]. It is a tree-like hierarchical structure similar to that on which the cooperation of bees in a hive and ants in an anthill is based. Unfair business practices, teamwork, resource management and planning were explained using analogies with the natural ecosystem, for which appropriate parallels with forest dwellers could be assigned. In addition, the subsequent research study could explore similarities in project financing, risks, changes, and control methods. Finally, practical recommendations for future project management pedagogy resulting from the results are given at the end of chapter 4.1. The experimental intervention at *UnivA* has led to higher point scores in achievement tests equaling a better mark. Therefore, the statistical test result supported the alternate hypothesis and rejected the null hypothesis.

3.1 Results of a qualitative research survey using focus groups

Focus Groups help reveal certain hidden and subsurface connections that we might overlook in other types of research [66]. For the results of the Focus Groups to be meaningful, it was necessary to let the students express their differing opinions eloquently using direct interaction [67]. Focus Group helped test new ideas, attitudes, values, most remarkable observations, and "aha moments" listed below. Individual agents are marked with the abbreviation A + No.

"Hierarchical position in human and wolf packs has its justified reason and thus ensures the pack's safety, food and well-being. Communication is clear and legible. Wolves can use their strengths, and other team members compensate for their weaknesses; this can be used well in the team as well." (A32)

"Finding food is a matter of economics. It will help if you consume less energy with it than you get from food. The longer you're on the road, the less it pays off. So, does it make sense to look for the shortest path?" (A17)

"I was interested in how the individual elements of the bee colony are perfectly interconnected: the bee colony will disappear without the mother, and the drones and the mother will perish without the workers. The worker alone cannot survive low temperatures, but the bee colony can easily survive severe frosts. Everything is linked together like WBS." (A78)

"Effective teamwork is clear from the wolves' hunting strategy; it is worth analysing the situation systematically rather than blindly chasing prey. Leadership transition, coaching, and mentoring produce well-experienced future leaders." (A65)

"Fox squirrels systematically store their supplies for the winter, sorting nuts according to type and quality. Similarly, the project manager should manage the project resources." (A19)

Focus Groups revealed deeper mind structures and cognitive action of emotions, specifically, how a particular impression affects attention, judgment, learning, and memory. If a specific learning objective was connected with an experience, it was better understood and remembered. It is clear from the participants' statements how students think about a problem, what opinions appear among them and what influences their opinion. The Focus Groups showed what was attractive to the participants and what they considered essential. They understood that time is critical in Project Management, as costs and resources depend on time management. The longer the project lasts, the more expensive it is. The most emotionally powerful was the video experience in which the parasitic fungus *Ophiocordyceps unilateralis* took control of *Camponotus* ants. Students understood that the learning process is continuous and could not finish in a single course. As a value-add, they also reported reduced shyness, relationship building, creative skills increase, stress, fear, fatigue, sadness or anger reduction.

4 DISCUSSION

The achievement test results indicate higher-point scores in the experimental (*UnivA*) group. It is now possible to answer *RQ1: Do forest parallels contribute to increased student engagement and better outcomes?* Student engagement can be understood as a positive, fulfilling state of mind associated with vigour, dedication and absorption and is manifested by active participation in academic activities and constructive communication with teachers [3], [22], [28]–[30]. An appropriate way to increase students' engagement is to create conditions in which they formulate and present their ideas, let them share their opinion and see how it fits into the surroundings [70]–[72]. Questions can be asked: In your opinion, which part of project management is your strong suit? The question is about *them*. Mass voting activated every student when it was necessary to determine the level of understanding of the whole class [31]–[32]. Voting was done simultaneously to ensure everyone voted and no one slipped by without participating.

The alternation of visual, auditory and kinesthetic teaching styles also contributes to the increase in engagement; the teacher-as-researcher implemented at least one activity for each learning style: illustrating concepts, taking notes, watching educational videos (visual), listening to podcasts, discussions (audial), experiments, movement in the forest (kinesthetic) [71]–[72].

The next step is to let students teach—giving them responsibility for the lecturing part of the curriculum. Sometimes, the teacher broke down the lesson's structure and allowed students to choose how to proceed.

Issues that were explained analogously on parallels with wild animal habits and behaviour, using action- and game-based learning and fieldwork increased the interest and involvement of students. In addition, attractive environments, high levels of immersion in these spaces and how the information is delivered increase the long-term impact on knowledge gained and social values, corresponding with other authors' findings [73]–[80]. Also, the involvement of experts from the project-oriented company and representatives of the employer sphere was desirable for transferring new knowledge from the practice to the higher education institutions and enabling a transition from school to the labour market. An expert from practice presents some topics and complements the interpretation with work experiences and the perspective of company practice [71]–[74].

4.1 Limitations and possible follow-up research

However, this study has limitations that could open future research avenues within a possible longitudinal study.

Pedagogical reality is different from physical or biological reality, and therefore experimentation in pedagogy is much more demanding than experimentation in technology or natural sciences [19], [42]–[45]. Controlling all the components (variables) in a pedagogical experiment is almost impossible because teachers deal with a living organism—a person [46]–[47]. Teaching students in such a way requires the teacher's deep interest and expertise in the life science field.

Focus Groups also have limitations. Dominant individuals can influence the opinion of the rest of the respondents. Some group participants may hide their points of view; conversely, other participants express more radical ideas, while in a personal conversation, they would not appear this way [66]. The presence of certain types of participants in the group will also influence the speech and opinions of others. The data obtained are also more demanding to analyse [67].

The Kolmogorov-Smirnov test also has several limitations: It is suitable for assessing differences in the composition (structure) of two groups. It is applicable in the case of so-called continuous random variables. However, when this test is applied to discrete random variables, its efficiency drops significantly: the Shapiro-Wilk test only works well in samples with many identical values [60]–[62].

This study is not a finished product - nor should it be given the constant research and development in the market. Some elements of the program—particularly fieldwork in nature—will require more time to achieve the appropriate level of effectiveness. Nevertheless, as the program matures, course content and methodology will continue to grow and evolve.

This paper aimed to compare the effectiveness of standard and experimental methods and approaches. Further research could encompass more parallels with nature and involve more participants, preferably from ten different public or private universities. It would create a reliable experimental plan where the results of all students taught by one method would be compared with those of all students prepared by the other method. However, this meta-analysis would be demanding to implement in practice.

Prior research studies using analogies with forests were minimal and focused on business economics [81]. This limitation is a challenging opportunity for further project management development. In addition, several research papers deal with the teaching methods of project management [1], [15], [19], [24]–[26]. Nevertheless, the purpose of this study was, among other things, to fill the gap with empirical research that would look at things through students' eyes.

4.2 Future project management pedagogy

Now it is possible to answer *RQ2: What are the findings and recommendations for future project management pedagogy?*

The student perspective should be considered in future pedagogy contexts within the discipline. The transformation should encourage the exchange of ideas between students and those who teach by involving the analogy method in daily education: showing examples from the great outdoors, how to manage resources, work together as a team, and how planning and looking for the shortest (i.e. cheapest) route pays. Let group dynamics work, shift the relationship with students as learner-centred, and teach students to use the proper techniques and tools for the right purpose. Lead them to understand that the project is intended to deliver a valuable product to the organisation that funds it. Processes and mechanisms of technology are the only means to achieve the goal. Students must understand that clearly defined roles and responsibilities of team members are essential; they learn to plan step by step and manage the project in stages. Students should be encouraged to look at the "big picture" and understand how the parts and pieces that make up the whole interact and influence each other. It is crucial because some of the biggest challenges facing our world today are the product of systems failure and require a systems approach to solutions.

The added value of nature-based activities is that students strengthen their relationship with green spaces and drive characteristics of self-efficacy, determination and independence, a sense of belonging to the community, tolerance and respect. This interaction and the cooperative feature of activities lead to increased social inclusion, lower isolation, greater trust, reciprocity, connectedness and social cohesion [34]–[36]. In line with transformative and social learning theories, educators must facilitate project management students to become co-creators rather than simply recipients of knowledge [19], [22]–[23]. Such requirements call for an emphasis on broader educational experiences. Changes in the institutions where project management is taught are also desirable. For example, educators need to adopt a different way of teaching by allowing engagement in project modules where students can become proactive problem solvers involving critical thinking. In addition, higher education institutions need to change their business models by supporting flexible learning, preparing students to meet real-world problems [82] and integrating them into the curriculum [83]–[84]

5 CONCLUSIONS

This research's urgency is evident from the growing gap between students' expectations and what universities are able or willing to provide [85]. Therefore, the learning objectives of the project management course are focused on tools and techniques to master the life cycle and procedures of planning, initiation, evaluation and termination of the project, time-resource analysis, risks, changes and control mechanisms. Although the objectives can be achieved through various methods, the research design of this study is based on parallels between the project ecosystem and the forest ecosystem. The rationale for this idea is that our world is made up of systems—from ecosystems in nature to organisations and technologies in human society [9]. Moreover, systems consist of interacting parts and relationships between those parts. Therefore, systemic thinking means considering the whole and its interacting parts in context [10].

The link to *RQ1,2* is as follows. First, the experiment revealed that if a specific learning objective was bound up with experience, it was better understood and remembered. The most emotionally powerful was the video experience in which the parasitic fungus *Ophiocordyceps unilateralis* dominated the *Camponotus* ants. Therefore, the students scored much higher on the unfair business practices in the achievement test than their colleagues from the parallel (control) group. Second, the more students observe from nature how to use resources and constraints, the better equipped they are for managerial practice. Third, the outdoor environment is informal [34]–[35], offering more suitable conditions for students to formulate and present insights and observations. Everyone could contribute their opinion and see how it fits into the group's atmosphere. Finally, issues explained analogically with parallels with forest dwellers increased student interest and engagement.

Recommendations for future project management pedagogy are based on the study's findings and designed in a flexible, multimodal methodology to meet a wide range of students' learning objectives and educational needs. This paper's results could be relevant for policymakers and stakeholders to develop successful strategies. Interpersonal skills are increasingly crucial over technical skills and their possible influence on managing complex oscillations within projects [86]. However, a particularly beneficial finding from this study is that those who need to learn such skills (students) accept this reality. In addition, this study identified the need for higher education institutions to rethink their way of integrating transferable skills into the educational agenda at all levels, full potential in educating students in line with their expectations and the growing demand for university education at a global level. Finally, this experiment proves that training people according to naturally inspiring principles that have worked for billions of years on earth makes sense.

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7 REFERENCES

[1] T. Mengel, "Outcome-based project management education for emerging leaders—A case study of teaching and learning project management," *International Journal of Project Management,* 26(3), 275–285, 2008. https://doi.org/10.1016/j.ijproman.2007.12.004

[2] A. Söderholm, "Project management of unexpected events," *International Journal of Project Management,* 26(1), 80–86, 2008. https://doi.org/10.1016/j.ijproman.2007.08.016

[3] E. Levin, P. Thaichon, S. Quach and A. Lobo, "The role of creativity and project management in enhancing service quality of advertising agencies: A qualitative approach," *Australasian Marketing Journal,* 26(1), 31–40, 2018. https://doi.org/10.1016/j.ausmj.2017.10.002

[4] I. Simonics, "Relationships among economy, industry, vocational education and training and higher engineering education—The trefort project editorial," *International Journal of Engineering Pedagogy (iJEP*), 10(5), 4–6, 2020. https://doi.org/10.3991/ijep.v10i5.16747

[5] S. Pathak, "Biomimicry: (Innovation Inspired by Nature)," *International Journal of New Technology and Research*, 5(6), 2019. https://doi.org/10.31871/IJNTR.5.6.17

[6] N. Kshetri, "The entrepreneurial ecosystem and its components," Global Entrepreneurship, 36–64, 2018. https://doi.org/10.4324/9780429458996-2

[7] J.N. Bhakta and Y. Munekage, "Role of ecosystem components in Cd removal process of aquatic ecosystem," *Ecological Engineering*, 32(3), 274–280, 2008. https://doi.org/10.1016/j.ecoleng.2007.12.004

[8] W. Visser and J.M. Benyus, "Biomimicry," *The Top 50 Sustainability Books*, 104–107, 2009.

[9] A. Lebdioui, "Nature-inspired innovation policy: Biomimicry as a pathway to leverage biodiversity for economic development," *Ecologiwengwecal Economics*, 202, 107585, 2022. https://doi.org/10.1016/j.ecolecon.2022.107585

[10] F. Chapin, P. Matson, P.M. Vitousek and M.C. Chapin, *Principles of terrestrial ecosystem ecology*. (2nd ed.). New York: Springer, 2011. ISBN 978-1-4419-9504-9. https://doi.org/10.1007/978-1-4419-9504-9

[11] A. Marshall, "Biomimicry," *Encyclopedia of Corporate Social Responsibility*, 174–174, 2013. https://doi.org/10.1007/978-3-642-28036-8_273

[12] I.C. Gebeshuber, "Biomimetics—prospects and developments," *Biomimetics*, 7(1), 29, 2022. https://doi.org/10.3390/biomimetics7010029

[13] F. Vazquez, "Welcome to the new journal biomimetics," *Biomimetics*, 1(1), 1, 2016. https://doi.org/10.3390/biomimetics1010001

[14] H. Witte, "The interplay of biomimetics and biomechatronics," *Biomimetics*, 7(3), 96, 2022. https://doi.org/10.3390/biomimetics7030096

[15] C. Bredillet, "Understanding the very nature of project management: A praxiological approach". Paper presented at PMI® Research Conference: Innovations, London, England. Newtown Square, PA: Project Management Institute, 2004.

[16] J.R. Turner, "Towards a theory of project management: The nature of the functions of project management," *International Journal of Project Management*, 24(4), 277–279, 2006. https://doi.org/10.1016/j.ijproman.2006.03.002

[17] D. Lock, "The nature and purpose of project management," *Project Management*, 3–19, 2018. https://doi.org/10.4324/9781315199764-1

[18] L. Sabini and N. Alderman, “The paradoxical profession: Project management and the contradictory nature of sustainable project objectives,” *Project Management Journal*, 52(4), 379–393, 2021. https://doi.org/10.1177/87569728211007660

[19] D. Geist and M. Myers, “Pedagogy and project management: Should you practice what you preach?” *J Comput Sci College*, 23(2), 202–208, 2007.

[20] J.S. Collofello, “University/industry collaboration in developing a simulation-based software project management training course,” Thirteenth Conference on Software Engineering Education and Training, 2000. https://doi.org/10.1109/CSEE.2000.827034

[21] S. Cicmil, T. Williams, J. Thomas and D. Hodgson, “Rethinking project management: Researching the actuality of projects,” *International Journal of Project Management,* 24(8), 675–686, 2006. https://doi.org/10.1016/j.ijproman.2006.08.006

[22] A. Hartmann, A. Dorée and L. Martin, “A constructivist approach for teaching research methodology in construction management,” *International Journal of Construction Education and Research*, 6(4), 253–270, 2010. https://doi.org/10.1080/15578771.2010.527181

[23] U. Ojiako, M. Ashleigh, M. Chipulu and S. Maguire, “Learning and teaching challenges in project management,” *International Journal of Project Management*, 29(3), 268–278, 2011. https://doi.org/10.1016/j.ijproman.2010.03.008

[24] R. Atkinson, “Excellence in teaching and learning project management,” *International Journal of Project Management*, 26(3), 221–222, 2008. https://doi.org/10.1016/j.ijproman.2008.02.001

[25] M. Gómez, R.F. Ángel, Herrera, E. Atencio and F.C. Munoz-La Rivera, “Key management skills for integral civil engineering education,” *International Journal of Engineering Pedagogy (iJEP),* 11(1), 64–77, 2021. https://doi.org/10.3991/ijep.v11i1.15259

[26] X. Zhao, “Towards effective teaching in project management,” Modern *Techniques for Successful I.T. Project Management*, 168–182, 2015. https://doi.org/10.4018/978-1-4666-7473-8.ch008

[27] B. Divjak and S.K. Kukec, “Teaching methods for international project management,” *International Journal of Project Management*, 26(3), 251–257, 2008. https://doi.org/10.1016/j.ijproman.2008.01.003

[28] S. Wearne, “Stakeholders in excellence in teaching and learning of project management,” *International Journal of Project Management*, 26(3), 326–328, 2008. https://doi.org/10.1016/j.ijproman.2008.02.002

[29] S. Sjøberg, “Constructivism and learning,” *International Encyclopedia of Education*, 485–490, 2010. https://doi.org/10.1016/B978-0-08-044894-7.00467-X

[30] L. Harasim, “Constructivist learning theory,” *Learning Theory and Online Technologies*, 61–79, 2017. https://doi.org/10.4324/9781315716831-5

[31] J. Schreurs and R. Dumbraveanu, “A shift from teacher centered to learner centered approach,” *International Journal of Engineering Pedagogy (iJEP*), 4(3), 36–41, 2014. https://doi.org/10.3991/ijep.v4i3.3395

[32] S. Chuang, “The applications of constructivist learning theory and social learning theory on adult continuous development,” *Performance Improvement*, 60(3), 6–14, 2021. Portico. https://doi.org/10.1002/pfi.21963

[33] L. Von Mises, “Human action: A treatise on *economics*,” Prague: Liberty Institute, 2018. ISBN 978-80-86389-61-5.

[34] E. Woodcock, “Rapid review: Nature-based activities and well-being,” 2017. Available: https://www.researchgate.net/publication/313818570_Rapid_Review_Nature-based_activities_and_well-being/citation/download. [Accessed March, 5, 2021]

[35] N.M. Ardoin, A.W. Bowers, N.W. Roth and N. Holthuis, “Environmental education and K-12 student outcomes: A review and analysis of research,” *The Journal of Environmental Education*, 49(1), 1–17, 2017. https://doi.org/10.1080/00958964.2017.1366155

[36] S. J. Cooley, V.E. Burns and J. Cumming, "The role of outdoor adventure education in facilitating group work in higher education," *Higher Education*, 69, 567–582, 2015. https://doi.org/10.1007/s10734-014-9791-4
[37] N. Hativa, "Active learning during lectures," *Teaching for Effective Learning in Higher Education*, 87–110, 2000. https://doi.org/10.1007/978-94-010-0902-7_7
[38] S. Karppinen, "Outdoor adventure education in a formal education curriculum in Finland: Action research application," *Journal of Adventure Education and Outdoor Learning*, 12(1), 41–62, 2012. https://doi.org/10.1080/14729679.2011.569186
[39] K. McFarlane, "Assessment, learning and employability," *Active Learning in Higher Education,* 5(3), 282–283, 2004. https://doi.org/10.1177/146978740400500309
[40] L. Remenick and L. Goralnik, "Applying andragogy to an outdoor science education event," *The Journal of Continuing Higher Education*, 67(1), 2436, 2019. https://doi.org/10.1080/07377363.2019.1629804
[41] W. Shooter, J. Sibthorp and J. Gookin, "The importance of trust in outdoor education: Exploring the relationship between trust in outdoor leaders and developmental outcomes," *Research in Outdoor Education*, 10, 48–56, 2010. https://doi.org/10.1353/roe.2010.0006
[42] M. Breunig, "Turning experiential education and critical pedagogy theory into praxis," *Journal of Experiential Education*, 28(2), 106–122, 2005. https://doi.org/10.1177/105382590502800205
[43] G.W. Ebbini, "Transformative design pedagogy: Teaching biophilic design through experiential learning," *Journal of Experiential Education*, 45(1), 7–31, 2021. https://doi.org/10.1177/10538259211019088
[44] A. Pau and V.S. Mutalik, "Experiential learning in community oral health promotion: A qualitative evaluation of the experiential aspects," *Pedagogy in Health Promotion*, 3(2), 108–114, 2016. https://doi.org/10.1177/2373379916655356
[45] I. Jirásek and I. Turčová, "Experiential pedagogy in the Czech Republic," *Experiential Learning and Outdoor Education,* 8–18, 2019. https://doi.org/10.4324/9780429298806-2
[46] T.O. Peterson and D.A. Lunsford, "Parallel thinking: A technique for group interaction and problem solving," *Journal of Management Education*, 22(4), 537–554, 1998. https://doi.org/10.1177/105256299802200409
[47] D. Türk, "Combined and parallel individual and group therapy—still a red rag?" *Group Analysis,* 52(3), 313–329, 2019. https://doi.org/10.1177/0533316419849503
[48] J.H. McMillan and S. Schumacher, *Research in Education*. New Jersey: Pearson, 2010. ISBN 978-0137152391.
[49] R. Revans, *The origin and growth of action learning*. Bromley: Chartwell Bratt Bromley, 1982. ISBN 9780862380205.
[50] P. Bychkov, M. Netesova and A. Sachkova, "Involving students in research with elements of game-based learning for engineering education," *Adv Int Syst Comput*, 716, 768–775, 2018. https://doi.org/10.1007/978-3-319-73204-6_84
[51] M. Milosz and J. Montusiewicz, "Game-based learning efficiency-study results of using the computerised board game 'Architectural Jewels of Lublin,'" In: *IEEE Global Engineering Education Conference* (ed. EEE EDUCON), Spain, April 2018, 1432–1437, 2018. EDUCON. https://doi.org/10.1109/EDUCON.2018.8363399
[52] A. Rachman and R.M.C. Ratnayake, "A game-based learning system to disseminate kanban concept in an engineering context: A case study from risk-based inspection project," In: IEEE *International Conference on Industrial Engineering and Engineering Management*, December 2017, 2296–2301. Singapore: IEEE. https://doi.org/10.1109/IEEM.2017.8290301
[53] V. Hargaden, N. Papakostas and J. Toomey, "An application of game-based learning in an electronics industry graduate training program," In: 2017 *International Conference on Engineering, Technology and Innovation*. ICE/ITMC 2017—Proceedings, January 2018, 284–289. Portugal: IEEE. https://doi.org/10.1109/ICE.2017.8279900

[54] M. Mavromihales, V. Holmes and R. Racasan, "Game-based learning in mechanical engineering education: A case study of games-based learning application in computer-aided design assembly," *International Journal of Mechanical Engineering Education*, 47(2), 156–179, 2018. https://doi.org/10.1177/0306419018762571

[55] S. Chandrasekaran and R. Al-Ameri, "Assessing team learning practices in project/design based learning approach," *International Journal of Engineering Pedagogy (iJEP)*, 6(3), 24–31, 2016. https://doi.org/10.3991/ijep.v6i3.5448

[56] M. Sharma and G. Singh, "Construction and standardization of achievement test in economics," *International Journal of Science and Research*, (IJSR), 4(12), 2072–2074, 2015. https://doi.org/10.21275/v4i12.NOV152491

[57] D. Schneider and N. Mather, "Achievement testing," *The Encyclopedia of Clinical Psychology*, 1–8, 2015. https://doi.org/10.1002/9781118625392.wbecp136

[58] A. Kaur, "Construction and standardisation of achievement test in English," *Scholarly Research Journal for Interdisciplinary Studies*, 4(37), 2017. https://doi.org/10.21922/srjis.v4i37.10785

[59] F. Franceschini, M. Galetto and M. Varetto, "Qualitative ordinal scales: The concept of ordinal range," *Quality Engineering*, 16(4), 515–524, 2004. https://doi.org/10.1081/QEN-120038013

[60] S. Shapiro and M.B. Wilk, "An analysis of variance test for normality (complete samples)," Biometrika, 52(3–4), 591–611, 1965. https://doi.org/10.1093/biomet/52.3-4.591

[61] G. Marsaglia, W.W. Tsang and J. Wang, "Evaluating Kolmogorov's Distribution," *Journal of Statistical Software*, 8 (18), 1–4, 2003. https://doi.org/10.18637/jss.v008.i18

[62] M. Fay and M.A. Proschan, "Wilcoxon–Mann–Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules," *Statistics Surveys*, 4, 1–39, 2010. https://doi.org/10.1214/09-SS051

[63] C. M. Salgado, C. Azevedo, H. Proença and S.M. Viera, "Missing Data," *Secondary Analysis of Electronic Health Records*, 143–162, 2016. https://doi.org/10.1007/978-3-319-43742-2_13

[64] J. Kaiser, "Dealing with Missing Values in Data," *Journal of Systems Integration*, 42–51, 2014. https://www.researchgate.net/publication/304500093_Dealing_with_Missing_Values_in_Data

[65] D.A. Bennett, "How can I deal with missing data in my study?" *Australian and New Zealand Journal of Public Health,* 25(5), 464–469, 2001. Portico. https://doi.org/10.1111/j.1467-842X.2001.tb00294.x

[66] Focus Groups, *The SAGE Encyclopedia of Qualitative Research Methods*, 2008. https://doi.org/10.4135/9781412963909.n178

[67] K. Then, J. Rankin and A. Effat, "Focus group research: What is it and how can it be used?" *Canadian Journal of Cardiovascular Nursing*, 24, 16–22, 2014.

[68] L. Chittka, "Current Biology," 20(23), PR1006–R1008, 2010. Available at: https://doi.org/10.1016/j.cub.2010.09.062

[69] T. Schwander, M. Beekman, B.P. Oldroyd and L. Keller, "Nature versus nurture in social insect caste differentiation," Trends Ecol Evol, 25, 275–282, 2010. https://doi.org/10.1016/j.tree.2009.12.001

[70] L.A. Jesper, J.F.D. Nielsen and C. Zhou, "Motivating students to develop satellites in problem and project-based learning (P.B.L.) environment," *International Journal of Engineering Pedagogy (iJEP)*, 3(3), 11–17, 2013. https://doi.org/10.3991/ijep.v3i3.2529

[71] M. Pinho-Lopes and J. Macedo, "Project-based learning to promote high order thinking and problem-solving skills in geotechnical courses," *International Journal of Engineering Pedagogy (iJEP)*, 4(5), 20–27, 2014. https://doi.org/10.3991/ijep.v4i5.3535

[72] M. Koivisto, "Gamified learning of project business skills," *International Journal of Advanced Corporate Learning (iJAC),* 15(1), 4560, 2022. https://doi.org/10.3991/ijac.v15i1.26689

[73] M. Kuo, M. Barnes and C. Jordan, "Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship," *Frontiers in Psychology*, 10, 2019. https://doi.org/10.3389/fpsyg.2019.00305
[74] M. Brody, "Learning in nature," *Environmental Education Research*, 11(5), 603–621, 2005. https://doi.org/10.1080/13504620500169809
[75] J. Dillon, "Barriers and benefits to learning in natural environments," *Cosmos*, 08(02), 153–166, 2013. https://doi.org/10.1142/S0219607712300056
[76] M. Genc, T. Genc and P.G. Rasgele, "Effects of nature-based environmental education on the attitudes of 7th-grade students towards the environment and living organisms and affective tendency," *International Research in Geographical and Environmental Education*, 27(4), 326–340, 2017. https://doi.org/10.1080/10382046.2017.1382211
[77] D.C. Berliner, "Learning about and learning from expert teachers," *International Journal of Educational Research*, 35(5), 463–482, 2001. https://doi.org/10.1016/S0883-0355(02)00004-6
[78] L.B. Flick and N.G. Lederman, "The role of practice in developing expertise in teaching," *School Science and Mathematics*, 101(7), 345–347, 2001. Portico. https://doi.org/10.1111/j.1949-8594.2001.tb17967.x
[79] P.S. Turocy, "The impact of instructor expertise and competency on student learning and strategies for improvement," *Athletic Training Education Journal*, 11(3), 158–160, 2016. https://doi.org/10.4085/1103158
[80] E. MacLellan and R. Soden, "Expertise, expert teaching and experienced teachers' knowledge of learning theory," *Scottish Educational Review*, 35(2), 110–120, 2003. https://doi.org/10.1163/27730840-03502003
[81] K. Macháčková, J. Zelený, D. Kolářová and Z. Vinš, "Nature ideas exchange: Education of sustainable business principles based on parallels with forest ecosystem," *Sustainability*, 13(9), 5306, 2021. https://doi.org/10.3390/su13095306
[82] K.C. Lim, S. Low, S. Attallah. P. Cheang and E. LaBoone, "A model for teaching, assessment and learning in engineering education for working adults," *International Journal of Advanced Corporate Learning*, 5(4), 16–21, 2012. https://doi.org/10.3991/ijac.v5i4.2249
[83] L. Manzione, A. Abu-ais heh, N. Sumukadas and S. Congden, "Preparing engineering students for the global sourcing environment, "*International Journal of Advanced Corporate Learning*, 10(1), 4–14, 2017. https://doi.org/10.3991/ijac.v10i1.5942
[84] G. Pasman and I. Mulder, "Bringing the everyday life into engineering education," *International Journal of Advanced Corporate Learning*, 4(1), 25–31, 2011. https://doi.org/10.3991/ijac.v4i1.1519
[85] C. McInnis, "New realities of the student experience: How should universities respond?" 25th Annual Conference, European Association for Institutional Research, Limerick, 24–27, August 2003.
[86] P. Patanakul, D. Milosevic and T. Anderson, "A decision support model for project manager assignments," *Engineering Management*, 54, 548–564, 2007. https://doi.org/10.1109/TEM.2007.900797

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PAPER

Implementing a Web Application Screener for Preschoolers: Executive Functions and School Readiness

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ABSTRACT

Web applications can be constructed to assess the executive functions and literacy skills of preschool aged children using a variety of research protocols. This work describes such a web application and its research protocol with tasks that screen inhibition, auditory and visual working memory, letter sound connection, word identification, and cognitive flexibility. The application was tested on a group of 65 preschoolers with cognitive deficits whose parents were advised to allow their children to reattend kindergarten classes and a control group of 65 typically achieving peers of similar age and gender. The results revealed that children at the age of four and five years old with cognitive deficits presented lower scores of correct answers and larger latencies in all six tasks compared to children that participated in the control group.

KEYWORDS

preschool children, web application screener, school readiness, executive functions

1 INTRODUCTION

Children's executive functions (EFs) develop rapidly throughout the first five years of life because they must learn to change their behavior in order to override automatic or ingrained ideas and responses [1]. Infants go through physical and cognitive changes. Infants' brains develop more quickly than any other part of the body, and by the time they are five years old, they weigh around 90% as much as an average adult brain does [2]. The two hemispheres of the brain begin to differentiate and they specialize in various tasks. The preschool years are when cerebral laterality becomes more apparent. It is backed by the fact that preschoolers' improved cognitive skills are correlated with both brain growth and the amount of myelin covering

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their brain neurons. The brain regions with the slowest rate of development, the prefrontal and frontal cortex, have been intimately associated with EFs.

In order to lay a crucial foundation for the development of higher cognitive processes far into later life stages (such as adulthood), core EFs emerge during the preschool years [2]. The various prefrontal cortex regions are closely linked to the various aspects of goal-oriented behavior [3]. Several studies have presented that the prefrontal cortex, which is in charge of EF development, increases noticeably during early childhood development. As a result, the fundamental elements that compose and serve as a key foundation for the formation of EFs can be identified even in children as young as four years old [2][4].

The emergence of nearly all cognitive, behavioral, and social-emotional functions occurs during sensitive times of fast brain development in infancy and early childhood [5]. The process of myelination, dendritic arborization, synaptogenesis, and synaptic pruning occurs during this time, shaping and honing the brain's expressive networks [6]. The brain activity that controls these adaptive processes makes them responsive to external, genetic, hormonal, and other stimuli [7]. The development and the pattern of myelination follows a well-described neuroanatomical arc, progressing from a posterior to anterior and center-outwards spatiotemporal pattern that corresponds to maturing cognitive functions [7]. The myelination of the brain areas and networks supporting a given cognitive function and its emergence share a lot of similarities [8]. Many studies in this field demonstrate the significance of white matter and cortical myelination for cognitive development and brain plasticity (e.g. [9]).

The rest of this paper is organized as follows. Section 2 discusses EFs in detail, focusing on their assessment, particularly through computer-based tests. Section 3 presents the testing methodology used in this research. The results obtained are presented and analyzed in Section 4. Final discussion and conclusions are given in Section 5.

2 EXECUTIVE FUNCTIONS AND THEIR ASSESSMENT

2.1 EFs

Although EFs are frequently discussed in neuropsychological studies, there is still no official definition of them. Contradictory results from studies examining the various facets of this construct have frequently been obtained, leaving uncertainty and even dispute over the genuine nature of executive talents [10]. The word "EFs" refers to a broad range of cognitive processes that help with goal-oriented behavior by controlling and coordinating information [11]. A more comprehensive definition of EFs refers to a family of top-down mental processes required when one needs to concentrate and focus attention in situations where depending on instincts or intuition would be unwise, insufficient, or impossible [12].

Despite their complexity, there is a general understanding of the complexity and significance of cognitive functions for adaptive behavior in humans. Cognitive skills enable attention shifting and adaption to a variety of events in a continually changing environment, while also thwarting inappropriate behavior [10]. Inhibition, attention shifting, updating, fluency, and planning are just a few of the higher order cognitive processes that are involved in the complex construct known as EFs.

The ability to control a response—or lack thereof—to a stimulus is referred to as inhibition. The capacity to switch from one job to another is shifting. The ability to monitor and control mental representations held in working memory is referred to as updating. Fluency is the capacity to produce a predetermined number of words in a predetermined amount of time based on semantic categories or phonemes. The ability to conceive, assess, and choose a series of ideas in order to accomplish a goal is referred to as planning.

The idea that EFs develop in a hierarchical fashion with attention serving as the basis is put forth by several studies that look at the development of EFs from infancy to the age of five years (e.g. [2]). According to early developmental EF studies, it is hypothesized that early simple skills like remembering information and delaying a response during the first three years of life create the foundation of their character [13]. According to the constructivist model of cognitive development, it is maintained that these simpler components combine into more complicated processes including inhibition, working memory, sustained attention, planning, rejecting distractions, and shifting that define mature EF abilities [3][14]. In accordance with this idea, Garon et al. hypothesized that more complex abilities that develop later such as shifting and planning are constructed from earlier abilities. For instance, shifting requires working memory and inhibition in addition to the ability to shift [13].

Many studies suggest that EF skills are essential for children's academic success from early infancy to adolescence [15][16][17][18]. Since the child is once again required to participate in regulated activities in a formal setting that call for self-control during the transition to kindergarten, a successful adaptation to kindergarten is a crucial developmental cornerstone. Pre-literacy and mathematical reasoning are influenced by executive functions more than IQ in terms of preparedness for the first grade, according to studies [19]. Research indicates that from elementary school through high school, working memory and inhibition each independently predict success in arithmetic and reading. As a result, it has been asserted that EFs are crucial for academic success across all school years [19].

The academic outcomes of kindergarten were predicted by preschoolers' levels of inhibition and cognitive flexibility, according to research that followed Head Start preschoolers through kindergarten. In another study including Head Start toddlers, it was discovered that EFs could predict improvements in math, vocabulary, and listening comprehension throughout the preschool years [20]. Furthermore, throughout this period of life, emergent literacy skills, including detection of letters and letter sounds, manipulation of phonemes and identifying words can predict early reading development and subsequent reading accomplishment [17]. Studies have demonstrated that children who start school with impairments in language and emergent literacy skills later commonly develop reading problems as well as underachievement in middle school and beyond [17].

2.2 Assessment of EFs

There are several paper pencil tests that assess executive functions and reading abilities of preschoolers to identify their school readiness. For example, in order to assess inhibition skills, the developmental neuropsychological assessment test NEPSY-II has an inhibition assessment subtest [21]. Furthermore, Wechsler Preschool and Primary School Scale of Intelligence IV includes subcomponents that assess working memory [22]. Cognitive flexibility can be measured by the semantic verbal fluency subtest that is included in Coimbra Neuropsychological Assessment Battery [23], according to Diamond [24][25]. Well-studied assessments of phonological awareness, phonological access, letter knowledge and print awareness are sub scales of the Preschool Comprehensive Test of Phonological and Print Processing [26].

The use of computer-based neuropsychological assessment has been significantly increased in clinical diagnosis practice across a variety of specialties, including the evaluation of neuroscience and cognition learning disabilities [27], human computer biological signals interaction [28], and neurologic patients [29]. It is possible to precisely control variables for measuring cognitive functions, such as reaction time, correct or incorrect responses, error types, and the administration of direct stimuli, when using computer-based neuropsychological assessment to diagnose various clinical disorders in neuroscience [27]. Children today appear to be more engaged in their education, since they have access to electronic tools to help them with their homework [27]. Information and communication technologies (ICT) in education can improve the effectiveness and efficiency of teaching and learning because they entail learning using technology rather than just learning about it [30]. A vital initial step in the effective prevention of developmental and socioemotional difficulties is the early detection of speech, language, and behavioral impairments or delays, and young children's cognitive and linguistic development has an impact on subsequent development and readiness for learning [27][31]–[36]. The best studied computer-based assessment for preschool aged children is CoPS. CoPS is constructed on eight test tasks: a task that assesses visual sequential memory for spatial and temporal positions, a task that assesses visual memory for colors, a task for visual sequential memory for shapes and colors, a task for visual sequential memory employing letter-like symbols, a task that assesses letter names and none word names, a task that assesses auditory memory, a task for phonological awareness and a task for auditory discrimination phonemes. CoPS is used mainly for cognitive assessment and reading development [37].

2.3 Motivation and present study

In the present study, in order to assess EFs of preschoolers, a battery of test tasks was constructed in order to assess their inhibition ability (by a go/no-go task), as well as their visual and auditory working memory and their cognitive flexibility (by a visuospatial task). Furthermore, apart from the core, two additional tasks of school readiness were designed across the two main domains as an assessment of reading abilities, by including a letter–sound correlation task and a word identification task [38].

In the field of assessment of cognitive functions of kindergarten-age children, web applications do not exist, to the best of our knowledge. The main goal of the present research protocol was to construct a battery of tests that can be delivered by internet in order to screen cognitive functions and literacy skills of preschool children. This type of computer technology can be used nearly everywhere because it can be automatically installed on any device with a web browser.

Since it is cross-platform by nature, there is no action required from the user in the event of an update. A web application also doesn't need proprietary software that restricts it to a certain platform and has a quick development cycle, making it easier to build and deploy than ordinary desktop applications. In addition, the size of the community makes it possible to consider new functionalities to address growing issues quickly.

The hypothesis of the present study was that Greek preschoolers that are already diagnosed by paper-and-pencil tests with cognitive deficits whose parents were advised to allow their children to reattend kindergarten classes, will also present lower performance and higher time latencies in both cognitive and reading tasks of the web application screener.

3 RESEARCH METHODOLOGY AND IMPLEMENTATION

3.1 Participants

A total of 130 preschoolers participated in this study. More specifically, the children recruited were 69 males four and five years old (M = 4.41 SD = 0.449) and 61 females four and five years old (M = 4.79 SD = 0.415). The preschoolers with cognitive deficits (N = 65) had been diagnosed by paper-pencil tests by the psychological service of the Center of Diagnosis, Assessment and Support in Central Greece (as required by Greek Law) and their parents were advised to allow their children to reattend Kindergarten classes. The control group (N = 65) was formed by randomly selected infants who attended the same Kindergarten with their average peers. They presented typical academic performance according to their teachers' ratings. All preschoolers that participated in the present study did not have a history of major medical illness, psychiatric disorder, or significant visual or auditory impairments according to their medical records kept by the kindergarten. The participants of the comparison group were matched for age and gender with preschoolers with cognitive deficits (1 cognitive deficit: 1 control).

All participants were recruited after reading informative newspaper articles, notifications regarding inside schools and attending informative school meetings. All participants were selected from the region of Central Greece and took the test at the computer laboratory of the Department of Informatics and Telecommunications of the University of Thessaly. Preschoolers with cognitive deficits completed the test in thirty minutes on average and typical achieving participants completed the screening procedure in twenty minutes on average. All human data included in this manuscript were obtained in compliance with the Helsinki Declaration and the guidelines of the Ethics and Deontology Committee of the University of Thessaly.

3.2 Material and procedure

A battery of six tasks was used to test each participant's inhibition, auditory and visual working memory, letter-sound association, word identification, and cognitive flexibility. Children undertook one training activity to become familiar with the testing technique before starting the main test procedure. Children had to click a picture in the practice activity in order to operate the mouse and become accustomed to the action.

The six tasks are described next:

a) Inhibition task: Children had to choose the target picture out of five that were given randomly in the task during the test. The target pictures were presented four times and the non-target pictures were presented ten times (see Figure 1).

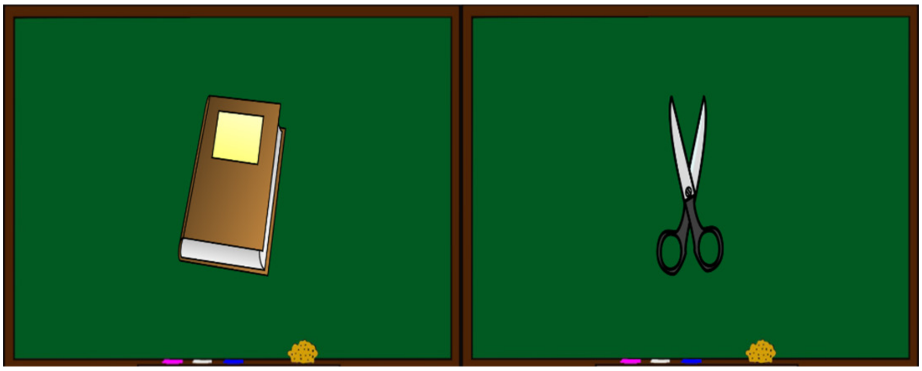

Fig. 1. Go/no-go task. Target picture (book), non-target e.g., scissors

b) Visual working memory task: Preschoolers had to remember 22 sequences of numbers during this task. The first sequence included three numbers; the second four numbers; the third five numbers; the fourth six numbers; the fifth seven numbers; the sixth eight numbers. Participants were asked to report the numbers with the use of a 0–9 numerical pad that was displayed. It is worth to mention that if children could not remember two series of numbers in a row or three series of numbers in general, the task was stopped (see Figure 2).

c) Auditory and Visual working memory task: This task consisted of twenty two sequences and was similar to the visual memory task, but the number sequences were given auditorily (see Figure 2).

d) Letter-sound task: Children had to select the phoneme that was auditorily delivered (10 phonemes) out of three graphemes.

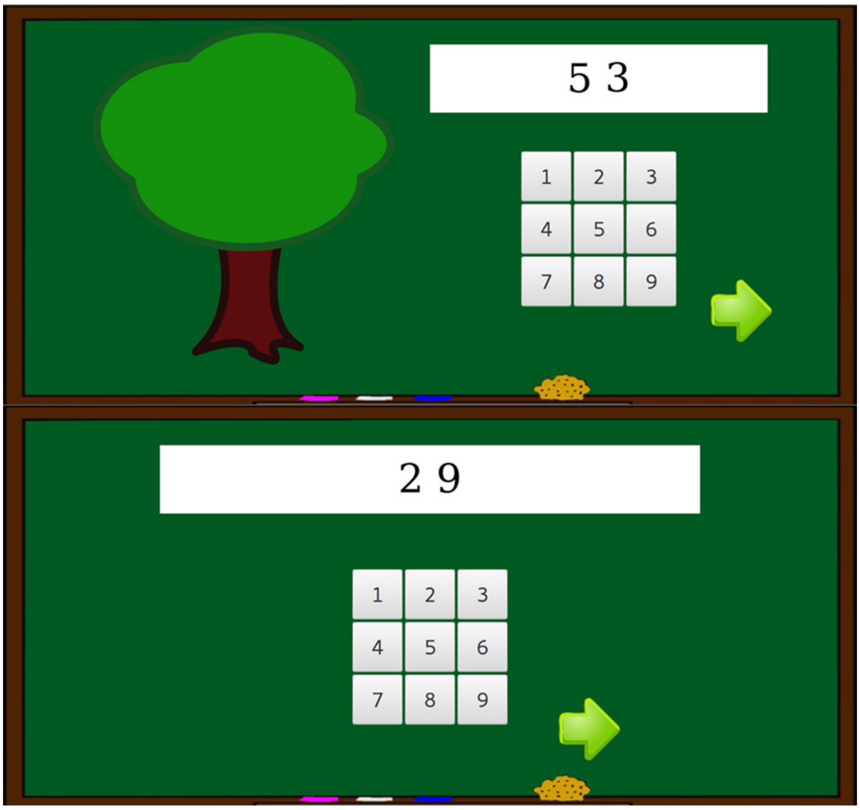

Fig. 2. Visual (upper part) and auditory (bottom part) working memory task

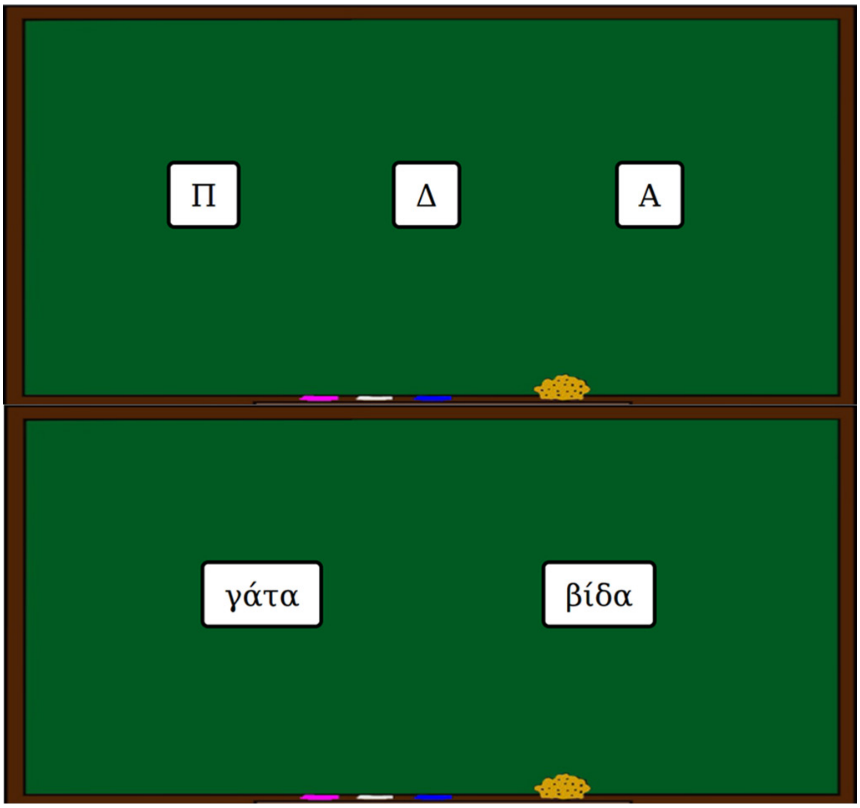

Fig. 3. Letter sound task (upper part) and word identification task (bottom part)

e) Word identification task: Children had to listen to a word (10 words in general) and decide which was the correct between two words that were presented. It must be highlighted that the words presented auditorily were commonly used and consisted of two syllables (see Figure 3).

f) Cognitive flexibility task: This assessment comprised a series of ten diagrams or patterns with a part missing and children were expected to select the correct part to complete the designs out of three options (see Figure 4).

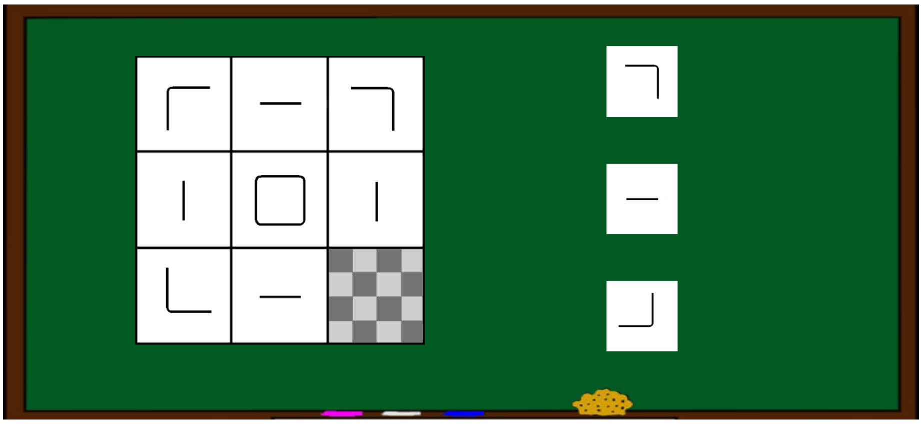

Fig. 4. Cognitive flexibility task. Pattern with a missing part in which children have to choose the correct from the three that are presented on the right

It is important to point out that every preschooler was able to operate the program successfully. From the first training task to the final testing procedure, they were able to operate the program with ease and efficiency because, prior to the assessment tasks, an illustration of the requirements of the subsequent process was provided to the kids.

Only technical concerns, such as entering the web application's URL, were made by the researchers.

3.3 Implementation

We deployed a client-server web application to provide a guided learning experience to students and to facilitate users with a unique browsing experience. Since our web application can be accessed by multiple users simultaneously, there is a constant communication demand between clients and the server that hosts the web application. To be more precise, every time a student finishes all six tests, all the intermediate results along with his/her basic personal information are saved for further inspection. Based on that, we select a minimum set of web technologies considering the maintenance, the reliability, and the performance of our web application. More specifically, for the client-side (frontend) we select HTML5, CSS3 and JavaScript to provide a user-friendly interface, while for the server-side (backend), we select PHP and MySQL to handle data storage and application logic.

HTML is the main markup language used for presenting and structuring content in a website. Its fifth version (HTML5) supports responsive design for mobile users, better performance for a website and compatibility between browsers. Moreover, the introduction of new tags replaces the need for installing third-party plugins for audio and video features while it replaces code snippets from other programming languages frequently used by web developers. For the beautification of our web application, we used Bootstrap. Bootstrap is the most-popular CSS framework for developing responsive web designs as it includes HTML and CSS design templates for typography, navigation, buttons, and forms. We select a color representation, keeping in mind simplicity to avoid confusing users, using green and white colors. We also used the same color palette for each test while we add contrast to draw attention to certain parts of the page. The core functionality of our application (i.e. screening tasks) was implemented using Vue.js that is a progressive JavaScript framework for building front-end interfaces. In Vue.js, a user can start a simple web page and progressively add tools and features that are needed for a demanding and complex web application like the one presented in this work. It also provides a way to build components that encapsulate data or a state on the JavaScript and then connect that state reactively in a template in HTML.

The back-end of our web application consists of a server, an application and a database. We used the PHP programming language to generate dynamic page content and to handle the communication between the client and the server. With PHP we managed to authenticate users using sessions and cookies that is one of the cornerstones of web security. Different capabilities were given regarding the role of each user. For instance, students can only enter their personal information and answer the relevant tasks, while the administrator can inspect preschooler scores, add new schools, create new classes etc. PHP also includes database support. Thus we select the MySQLi PHP extension to connect to a MySQL server. Using the appropriate queries, we save student answers into the database to be used for statistical analysis. Our web application has been enhanced to protect and secure sensitive information that is passing through different types of online channels. To achieve this, we implement secure SQL statements by using escaping and prepared statements, we support input validation using data type, format and value validation from both front-end and back-end using JavaScript and PHP respectively, and we apply multi-factor authentication and access control (e.g. a student is logged out when he/she tries to access more sensitive features). As current privacy regulations require the protection of sensitive data, we encrypt user personal information and student answers. To achieve that we encrypt sensitive information using a strong one-way hashing algorithm. The adaptive bcrypt password-hashing function was selected which adds a random salt to prevent rainbow tables and dictionary attacks. Finally, all data exchanged between clients and server were encrypted using the HTTPS protocol.

3.4 Data analysis

Descriptive statistics were performed in order to obtain mean scores and standard deviations of participants for all six tasks, as the training test was excluded from the statistical analysis. Prior to performing any statistical analysis, a Kolmogorov-Smirnov test in order to find the normality of collected data, as well as a Levene's test for homogeneity of variances were calculated. Analysis of Variance was the statistical analysis that was selected, due to the sample of the participants (N = 130) and their splitting in two groups.

4 RESULTS

Analysis of Variance (ANOVA) was conducted to compare the scores of children according to their group. Table 1 presents the mean scores and standard deviations for the correct responses to the six tasks. Furthermore, the table presents time latency and the statistical significance of the correct answers and time latency of children with cognitive deficits versus the control group. It must be highlighted that in inhibition tasks, visual and auditory working memory tasks latency was not measured.

Table 1. Mean scores and standard deviations of correct responses and time latency in seconds with the associated statistical significance for all tasks

Tasks	Groups				F
	Children with Cognitive Deficits		Control Group		
	Mean	SD	Mean	SD	
Inhibition Task	1.11	1.13	2.38	0.93	49.284*
Visual Working Memory Task	0.68	0.66	1.15	1.31	6.923*
Auditory Working Memory Task	1.77	1.64	4.15	0.87	106.556*
Letter Sound Connection Task	4.20	0.93	6.09	1.11	83.588*
Letter Sound Connection Task Latency	0.64	0.51	0.45	0.26	7.154*
Word Identification Task	5.44	1.25	7.15	1.36	34.497*
Word Identification Task Latency	0.45	0.39	0.22	0.87	21.382*
Cognitive Flexibility Task	4.45	0.88	5.15	1.03	19.192*
Cognitive Flexibility Task Latency	1.32	0.51	1.20	0.47	1.292

Note: *$p < 0.01$.

ANOVA revealed that children with cognitive deficits had statistically significant ($p < 0.01$) lower mean scores of correct answers in all six tasks compared to the control group. It must be noted that children with cognitive deficits presented statistically significant ($p < 0.01$) higher time latency in seconds for letter-sound connection and word identification tasks in comparison to children that participated in the control group. Although children with cognitive deficits presented higher time latency in seconds in cognitive flexibility in comparison to children that were recruited as control group, we did not find statistically significant results ($p > 0.05$). It must be mentioned that in inhibition task, auditory and visual memory tasks time latencies were not calculated.

EFs develop particularly rapidly (as early as infancy) and undergo protracted development into early adulthood as well as during the critical age period that was examined. Because of the above, researchers decided to apply ANOVA to groups of children according to their age. In more detail, it compared children of 4 years of age with cognitive deficits only to their average peers and children with cognitive deficits of 5 years of age to their respective average peers. The analysis revealed that both groups of children with cognitive deficits presented statistically significant ($p < 0.01$) lower scores in all six tasks in comparison to the control group. Also, they presented statistically significant larger latencies ($p < 0.05$) in the three tasks for which the time latency was recorded. Lastly, Cronbach's alpha was measured in order to find the internal consistency of all six tasks (not for latency) and was estimated $\alpha = 0.77$.

5 DISCUSSION

The web application screener that was used revealed significant differences ($p < 0.01$) in all six tasks that were constructed between preschoolers with cognitive deficits and the control group. In more detail, preschoolers with cognitive deficits presented statistically significant lower scores in comparison to the control group, a result that verifies our first hypothesis. Furthermore, preschoolers with cognitive deficits presented larger latencies in all three tasks for which time was recorded, in comparison to the control group, but the statistically significant latencies ($p < 0.01$) were observed during the letter sound connection task and word identification task, whereas the latency of cognitive flexibility task did not present significant differences between the two groups of children. The latency of cognitive flexibility task might be affected by the complexity of the diagrams and patterns that were chosen, as participants in both groups had difficulties in choosing the correct answer. This result partly verifies our second hypothesis.

However, it must be noted that through separation according to age (only children of four years of age and five years of age with cognitive deficits and their respective comparison group), it was observed that children with cognitive deficits presented statistically significant lower scores ($p < 0.01$) in all six tasks and statistically significant larger latencies in three tasks for which time was recorded ($p < 0.05$) in comparison to their average peers.

EF and school readiness skills are of utmost concern. In order to effectively promote school success for all children, it is necessary to better understand the underlying factors which contribute to early lapses in school readiness. The purpose of the current study was to present the relation between EFs of preschoolers and academic readiness. The results confirmed our hypothesis for correct answers and partly for higher latencies.

The fact that children with cognitive deficits can be screened for using a computer-based neuropsychological testing that is administered online was another significant finding of the current study. Computers are increasingly being used in psychology and education to identify children with EF problems. The main benefit of computer-based systems over traditional diagnostic techniques is the accuracy of the evaluation of cognitive abilities. Computers can significantly reduce the amount of time and effort required by scoring performance in terms of accurate or erroneous answers as well as time lag [30].

In a meta–analysis Sala and Gobet showed that training studies based on working memory intervention led to improvement in working memory [44]. Motivation likely plays a crucial role in determining training success. Previous research has shown better training success in children with gamified designs [45][46]. Web applications could be beneficial not only in screening but also as intervention programs by targeting the "players" motivation with training core mechanisms of EFs [27][47].

A diagnosis made by a qualified professional, or even better, by a multidisciplinary team of experts with a variety of talents, such as psychologists, educational diagnosticians, or other licensed professionals, cannot be totally replaced by a web-based exam screener. It is preferable for an efficient assessment of a student's abilities, limitations, level of academic performance at the time and eligibility for special education services. The interdisciplinary team that may conduct assessments may also design the intervention program that kindergarten students and infants with low academic success must adhere to [38][48]. The web-based screeners, on condition that are valid, can only be a supporting tool at the diagnosis.

In reviewing the findings of this investigation, the reader should bear in mind some of the study's methodological limitations. First, despite the fact that all participating preschoolers with cognitive deficits had received a formal diagnosis from a state diagnostic facility, the study team was unable to access their results of the diagnostic tests due to the applicable data privacy legislation. Furthermore, causality conclusions should be avoided because the data were collected at a single timepoint. To confirm these results, answer the causation query, and determine whether one process influences another over time, more longitudinal study is necessary. Second, we tried to design and implement a web application that measured EFs and pre-literacy abilities of preschoolers drawn from theoretical models and did not use well-established paper pencil tests in order to combine our findings.

In conclusion, the pre-literacy and EF web application screener created and employed for the current research protocol can be used as a screening tool to give first-pass service and referral. Additionally, this research supports previous findings that children with low academic achievement have problems not only with language skills but also with more fundamental capabilities like cognitive ability. Before its general adoption can be advised, the screening technique must also undergo a rigorous psychometric evaluation, the validity of the results of which are now being developed.

6 REFERENCES

[1] N. Garon, S. E. Bryson, and I. M. Smith, "Executive function in preschoolers: a review using an integrative framework". Psychological Bulletin, 134(1), 31, 2008. https://doi.org/10.1037/0033-2909.134.1.31

[2] M. M. Mesulam, "The human frontal lobes: transcending the default mode through contingent encoding". Principles of Frontal Lobe Function, 54, 8–30, 2002. https://doi.org/10.1093/acprof:oso/9780195134971.003.0002

[3] K. C. Brocki, and G. Bohlin, "Executive functions in children aged 6 to 13: A dimensional and developmental study". Developmental Neuropsychology, 26(2), 571–593, 2004. https://doi.org/10.1207/s15326942dn2602_3
[4] A. Diamond, "Executive functions. Annual review of psychology", 64, 135–168, 2013. https://doi.org/10.1146/annurev-psych-113011-143750
[5] M. H. Johnson, "Functional brain development in humans". Nature Reviews Neuroscience, 2(7), 475–483, 2001. https://doi.org/10.1038/35081509
[6] S. Deoni, D. Dean III, S. Joelson, J. O'Regan, and N. Schneider, "Early nutrition influences developmental myelination and cognition in infants and young children". Neuroimage, 178, 649–659, 2018. https://doi.org/10.1016/j.neuroimage.2017.12.056
[7] J. Stiles, and T. L. Jernigan, "The basics of brain development". Neuropsychology Review, 20(4), 327–348, 2010. https://doi.org/10.1007/s11065-010-9148-4
[8] E. Fornari, M. G. Knyazeva, R. Meuli, and P. Maeder, "Myelination shapes functional activity in the developing brain". Neuroimage, 38(3), 511–518, 2007. https://doi.org/10.1016/j.neuroimage.2007.07.010
[9] X. Dai, P. Hadjipantelis, J. L. Wang, S. C. Deoni, and H. G. Müller, "Longitudinal associations between white matter maturation and cognitive development across early childhood." Human Brain Mapping, 40(14), 4130–4145, 2019. https://doi.org/10.1002/hbm.24690
[10] M. B. Jurado, and M. Rosselli "The elusive nature of executive functions: a review of our current understanding." Neuropsychology Review, 17(3), 213–233, 2007. https://doi.org/10.1007/s11065-007-9040-z
[11] P. Anderson, "Assessment and development of Executive Function (EF) during childhood". Child Neuropsychology, 8(2), 71–82, 2002. https://doi.org/10.1076/chin.8.2.71.8724
[12] P. W. Burgess, and J. S. Simons, "18 Theories of frontal lobe executive function: clinical applications". The Effectiveness of Rehabilitation for Cognitive Deficits, 211, 2005. https://doi.org/10.1093/acprof:oso/9780198526544.003.0018
[13] N. Garon, I. M. Smith, and S. E. Bryson, "A novel executive function battery for preschoolers: Sensitivity to age differences". Child Neuropsychology, 20(6), 713–736, 2014. https://doi.org/10.1080/09297049.2013.857650
[14] R. Case, "Stages in the development of the young child's first sense of self". Developmental Review, 1991. https://doi.org/10.1016/0273-2297(91)90010-L
[15] J. E. Dilworth-Bart, "Does executive function mediate SES and home quality associations with academic readiness?" Early Childhood Research Quarterly, 27(3), 416–425. 2012. https://doi.org/10.1016/j.ecresq.2012.02.002
[16] T. D. Mann, A. M. Hund, M. S. Hesson-McInnis, and Z. J. Roman, "Pathways to school readiness: Executive functioning predicts academic and social–emotional aspects of school readiness". Mind, Brain, and Education, 11(1), 21–31, 2017. https://doi.org/10.1111/mbe.12134
[17] I. Korucu, E. Litkowski, and S. A. Schmitt, "Examining associations between the home literacy environment, executive function, and school readiness". Early Education and Development, 31(3), 455–473, 2020. https://doi.org/10.1080/10409289.2020.1716287
[18] R. Distefano, E. C. Schubert, M. C. Finsaas, C. D. Desjardins, C. K., Helseth, et al., "Ready? Set. Go! A school readiness programme designed to boost executive function skills in preschoolers experiencing homelessness and high mobility". European Journal of Developmental Psychology, 17(6), 877–894, 2020. https://doi.org/10.1080/17405629.2020.1813103
[19] S. Shaul, and M. Schwartz, "The role of the executive functions in school readiness among preschool-age children." Reading and Writing, 27(4), 749–768, 2014. https://doi.org/10.1007/s11145-013-9470-3

[20] I. Nayfeld, J. Fuccillo, and D. B. Greenfield, "Executive functions in early learning: extending the relationship between executive functions and school readiness to science." Learning and Individual Differences, 26, 81–88, 2013. https://doi.org/10.1016/j.lindif.2013.04.011

[21] M. Korkman, U. Kirk, and S. Kemp, "NEPSY-II: administration manual." San Antonio, TX: The Psychological Corporation, 2007.

[22] D. Wechsler, "Wechsler intelligence scale for children (4th ed.)". San Antonio, TX: The Psychological, 2003. https://doi.org/10.1037/t15174-000

[23] M. R. Simões, C. Albuquerque, M. Pinho, M. Pereira, M. Seabra-Santos, and I. Alberto, "Coimbra Neuropsychological Assessment Battery—CNAB (Bateria de Avaliação Neuropsicológica de Coimbra (BANC))". Lisboa: Cegoc, 2013.

[24] A. Diamond, "Executive functions". Annual review of psychology, 64, 135–168, 2013. https://doi.org/10.1146/annurev-psych-113011-143750

[25] M. G. Filipe, A. S. Veloso, and S. Frota, "Executive functions and language skills in preschool children: the unique contribution of verbal working memory and cognitive flexibility". Brain Sciences, 13(3), 470, 2023. https://doi.org/10.3390/brainsci13030470

[26] C. Lonigan, J. Wagner, and C. Rashotte, "The preschool comprehensive test of phonological and print processing". Tallahassee, FL: Florida State University, 2002.

[27] N. C. Zygouris, F. Vlachos, A. N. Dadaliaris, P. Oikonomou, G. I. Stamoulis, et al., "A neuropsychological approach of developmental dyscalculia and a screening test via a web application". International Journal of Engineering Pedagogy (iJEP), 7(4), 51–65, 2017. https://doi.org/10.3991/ijep.v7i4.7434

[28] V. Meza-Kubo, A. L. Morán, I. Carrillo, G. Galindo, and E. García-Canseco, "Assessing the user experience of older adults using a neural network trained to recognize emotions from brain signals". Journal of Biomedical Informatics, 62, 202–209, 2016. https://doi.org/10.1016/j.jbi.2016.07.004

[29] K. Fliessbach, C. Hoppe, U. Schlegel, C. E. Elger, and C. Helmstaedter, "NeuroCogFX—a computer-based neuropsychological assessment battery for the follow-up examination of neurological patients". Fortschritte der Neurologie-Psychiatrie, 74(11), 643–650, 2006. https://doi.org/10.1055/s-2006-932162

[30] A. Drigas, and E. I. Rodi, "Special education and ICTs." International Journal of Emerging Technologies in Learning (Online), 8(2), 41, 2013. https://doi.org/10.3991/ijet.v8i2.2514

[31] C. Galarce-Miranda, D. Gormaz-Lobos, and H. Hortsch, "An analysis of students' perceptions of the educational use of ICTs and educational technologies during the online learning". International Journal of Engineering Pedagogy (iJEP), 12(2), 62–74, 2022. https://doi.org/10.3991/ijep.v12i2.29949

[32] N., Kristianti, and N. Purnawati, "Virtual education with puzzle games for early childhood: a study of Indonesia". International Journal of Engineering Pedagogy, 8(2) 2018. https://doi.org/10.3991/ijep.v8i2.7943

[33] R. Rasmitadila, W. Widyasari, M. Humaira, A. Tambunan, R. Rachmadtullah, and A. Samsudin, "Using Blended Learning Approach (BLA) in inclusive education course: a study investigating teacher students' perception". International Journal of Emerging Technologies in Learning (IJET), 15(2), 72–85, 2020. https://doi.org/10.3991/ijet.v15i02.9285

[34] F. Bellotti, R. Berta, & A. De Gloria, "Designing effective serious games: opportunities and challenges for research". International Journal of Emerging Technologies in Learning (iJET), 5, 2010. https://doi.org/10.3991/ijet.v5s3.1500

[35] N. Pugacheva, T. Kirillova, O. Kirillova, A. Luchinina, I. Korolyuk, and A. Lunev, "Digital paradigm in educational management: the case of construction education based on emerging technologies". International Journal of Emerging Technologies in Learning (iJET), 15(13), 96–115, 2020. https://doi.org/10.3991/ijet.v15i13.14663

[36] Z. J. Liu, N. Tretyakova, V. Fedorov, and M. Kharakhordina, "Digital literacy and digital didactics as the basis for new learning models development". International Journal of Emerging Technologies in Learning (iJET), 15(14), 4–18, 2020. https://doi.org/10.3991/ijet.v15i14.14669

[37] C. Singleton, K. Thomas, and J. Horne, "Computer-based cognitive assessment and the development of reading". Journal of Research in Reading, 23(2), 158–180, 2000. https://doi.org/10.1111/1467-9817.00112

[38] N. C. Zygouris, K. Botsoglou, A. N. Dadaliaris, G. Dimitriou, D. Trontsios, et al., "Screening Executive Functions of Preschool Children via a Web Application." Educating Engineers for Future Industrial Revolutions: Proceedings of the 23rd International Conference on Interactive Collaborative Learning (ICL2020), Volume 1 23. Springer International Publishing, 2021. https://doi.org/10.1007/978-3-030-68198-2_12

[39] G. Galindo-Aldana, V. Meza-Kubo, G. Castillo-Medina, I. Ledesma-Amaya, J. Galarza-Del-Angel, et al. "Computer-based neuropsychological assessment: a validation of structured examination of executive functions and emotion." Engineering Psychology and Cognitive Ergonomics: 15th International Conference, EPCE 2018, Held as Part of HCI International 2018, Las Vegas, NV, USA, July 15–20, 2018, Proceedings 15. Springer International Publishing, 2018.

[40] E. I. Toki, and J. Pange, "E-learning activities for articulation in speech language therapy and learning for preschool children". Procedia-Social and Behavioral Sciences, 2(2), 4274–4278, 2010. https://doi.org/10.1016/j.sbspro.2010.03.678

[41] G. Kokkalia, A. Drigas, A. Economou, and P. Roussos, "Screening tools for kindergarten children". International Journal of Recent Contributions from Engineering, Science & IT (iJES), 5(4), 76–87, 2017. https://doi.org/10.3991/ijes.v5i4.8013

[42] H. Juhani Lyytinen, M. Semrud-Clikeman, H. Li, K. Pugh, and U. Richardson, "Supporting acquisition of spelling skills in different orthographies using an empirically validated digital learning environment". Frontiers in Psychology, 12, 675, 2021. https://doi.org/10.3389/fpsyg.2021.566220

[43] G. Sala, and F. Gobet, "Working memory training in typically developing children: a meta-analysis of the available evidence." Developmental Psychology, 53(4), 671, 2017. https://doi.org/10.1037/dev0000265

[44] V. E. Johann, and J. Karbach, "Effects of game-based and standard executive control training on cognitive and academic abilities in elementary school children". Developmental Science, 23(4), e12866, 2020. https://doi.org/10.1111/desc.12866

[45] K. Ganesan, and N. Steinbeis, "Development and plasticity of executive functions: A value-based account". Current Opinion in Psychology. (Journal pre-proof), 2021. https://doi.org/10.1016/j.copsyc.2021.09.012

[46] B. Chimmalee, and A. Anupan, Enhancement of mathematical conceptual understanding in a cloud learning environment for undergraduate students. International Journal of Engineering Pedagogy, 12(6), 2022. https://doi.org/10.3991/ijep.v12i6.33775

[47] N. C. Zygouris, G. I. Stamoulis, F. Vlachos, D. Vavougios, A. N. Dadaliaris, et al., "Screening for Disorders of Mathematics via a web application". In 2017 IEEE Global Engineering Education Conference (EDUCON) (pp. 502–507). IEEE, 2017, April. https://doi.org/10.1109/EDUCON.2017.7942893

[48] N. C. Zygouris, F. Vlachos, A. N. Dadaliaris, P. Oikonomou, et al., "The implementation of a web application for screening children with dyslexia." In International Conference on Interactive Collaborative Learning (pp. 415–423). Springer, Cham, 2017. https://doi.org/10.1007/978-3-319-50340-0_36

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PAPER

Problem-Based Learning. Application to a Laboratory Practice in the Degree of Industrial Chemical Engineering

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ABSTRACT

The transformation of university teaching towards a competency acquisition approach requires an update of teaching methodologies. In the case of laboratory practices, the application of the Problem-Based Teaching methodology encourages students to apply their knowledge to solve problems based on real situations, as well as efficient communication in a work environment. This paper presents the results obtained by applying this alternative teaching methodology to a laboratory practice in the last year of the Degree in Industrial Chemical Engineering at the University of La Laguna. The results confirm a greater theoretical understanding of the concepts and the ability to apply them in practice, with a notable increase in motivation and interest in their learning process.

KEYWORDS

motivation, cooperative learning, higher education, Chemical Engineering

1 INTRODUCTION

The convergence of university education to the European Higher Education Area (EHEA) has produced a transformation in learning practices based on active methodologies and collaborative processes, rather than on simple "encyclopaedic" and memorial learning, which calls for a real challenge on how engineering education should be approached [1]. Critical thinking, troubleshooting, autonomy, self-reliance, and communication are skills that are highly valued by the business sector, and the curricula of the subjects taught in Chemical Engineering degrees aim to perfect these skills in those subjects that are mainly practical. However, employers detect deficiencies in these skills in Chemical Engineering graduates [2]. Moreover, traditional learning must be transformed in order to adapt graduates to the current challenges of society such as technical globalization. In other words, teaching must not

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only offer a reinforcement of the practical contents of the degrees, but also improve the connection between theoretical and practical contents [3]. The development of certain professional skills requires the introduction of new learning innovation methods. Problem-based learning, self-learning and the introduction of collaborative activities among students are new learning methodologies that are beginning to be widely applied in engineering learning [4]. In practical disciplines such as Chemical Engineering, key skills and transversal competencies can be acquired through problem-based learning [5]. Problem-based learning (PBL) is an educational approach that uses real-world problem solving to enhance students' motivation as well as to promote the assimilation of concepts they need to know [3].

Problem-based learning is built on a socio-constructive learning framework [6], which is based on posing an open-ended problem to students without an obvious solution. In this scenario, students in a guided learning period must plan how to find and implement a solution. This type of methodology allows students to conduct research, integrate theory and practice, and apply knowledge and skills to develop a feasible solution to a defined problem [7]. The PBL methodology can be structured in three phases (I) problem analysis and diagnosis, (II) autonomous study of the problem and (III) solution proposal, which allows students to acquire the new competencies that will be required in their professional exercise [8].

The role of the learner in problem-based teaching methodology is completely different from the traditional role where the learner acts as a supervisor and transmitter of knowledge. In problem-based teaching, the teacher must create or design an appropriate environment for students to manage their own learning and explore the relevant subject matter [9]. The aim of this methodology is to enable students to learn how to apply theoretical concepts in realistic and complex situations, while the teacher provides the necessary guidance for students to achieve the desired results [2]. Under this new scenario, student motivation and commitment are key to achieving the objectives set. Motivation is a broad and complex field of work, being a key factor when designing and applying the problem-based learning methodology [10]. However, most authors confirm that giving learners control over their learning significantly increases their motivation [2], [11], [12]. In this learning context, reinforcing student motivation is key for students to fully enjoy the methodology.

In recent years, the use of problem-based learning has become very common in engineering education curricula. For example, at the University of Minho (Portugal) a multidisciplinary system was implemented in the first year of the Master of Engineering and Industrial Management curriculum [13], [14]. At the University of Brasilia (Brazil), the PBL methodology is used in the final year of the master's degree in chemical engineering [15] and at the University of Seville it has been used for the design and development of a pilot plant project [1]. And it has been applied in various fields such as cloud computing [16], physics [17], and even elementary education [18]. All authors have reported improved learning, increased student participation and that PBL seems to be the way forward to improve the skills of students.

The laboratory practice subjects are key in the training of a Chemical Engineer, as they provide a practical component necessary in their professional practice. In traditional systems, students follow a preconceived experimental procedure designed by the instructor where the results are expected, and the methodology is based on learning through data collection and analysis. However, it does not reinforce the connections between theory and the real world, preventing the development of new skills for the students. Clearly, during the first years of the degree, it is necessary to maintain a standard methodology for students to acquire and internalise basic concepts as already included in most chemical engineering curricula [19]. However, it is important to change the philosophy of the practical subjects during the final years so that students reflect on the knowledge acquired and allow them to develop the new skills required by the industrial sector. Recently, at the University of British Columbia, PBL methodology has been implemented in practical subjects, which consisted of confronting students with a real problem in order for them to decide and design an analysis plan that would allow them to draw their own conclusions [2]. The results found show that the approach used allows for the promotion of all the new skills described above.

The aim of this study is to analyse problem-based learning in the development of a laboratory practical in final year students of the Degree in Chemical Engineering, focusing on the students' impressions when faced with a real problem and on the improvement in the assimilation of the concepts developed in the practical.

2 MATERIALS AND METHOD

2.1 Experimentation in Industrial Chemical Engineering II

The problem-based learning methodology was analysed in a laboratory practice that is part of the subject Experimentation in Chemical Engineering II, which is taught in the last year of the Chemical Engineering Degree at the University of La Laguna. It has a total of 6 ECTS credits. The competencies to be developed in the subject according to order CIN 351/2009, which establishes the requirements for the verification of university degrees that enable Industrial Technical Engineers to practise professionally, are described in Table 1.

Table 1. Competencies of the subject Experimentation in Chemical Engineering II

Type	Skills
Specific	Ability to design and manage applied experimental procedures, especially for the determination of thermodynamic and transport properties and modelling of phenomena and systems in the field of chemical engineering, fluid flow systems, heat transfer, matter transfer operations, kinetics of chemical reactions and reactors.
Generals	Knowledge of basic and technological subjects, enabling them to learn new methods and theories, and giving them the versatility to adapt to new situations.
	Ability to solve problems with initiative, decision-making, creativity, critical thinking and to communicate and transmit knowledge, skills and abilities in the field of Industrial Chemical Engineering.
	Knowledge for carrying out measurements, calculations, valuations, appraisals, valuations, surveys, studies, reports, work plans and other similar work.
	Ability to work in a multilingual and multidisciplinary environment.
Transversals	Ability to analyse and synthesise.
	Ability to organise and plan time.
	Ability to oral expression.
	Ability to write expression.
	Ability to apply knowledge to practice.
	Ability to work effectively in a team.

(Continued)

Table 1. Competencies of the subject Experimentation in Chemical Engineering II *(Continued)*

Type	Skills
Basic	Students have demonstrated knowledge and understanding in an area of study that builds on the foundation of general secondary education, and is usually at a level that, while relying on advanced textbooks, also includes some aspects that involve knowledge from the cutting edge of their field of study.
	That students know how to apply their knowledge to their work or vocation in a professional manner and possess the competencies that are usually demonstrated through the elaboration and defence of arguments and problem solving within their area of study.
	Students have the ability to gather and interpret relevant data (usually within their area of study) in order to make judgements that include reflection on relevant social, scientific or ethical issues.
	Students are able to transmit information, ideas, problems and solutions to both specialised and non-specialised audiences.
	That students have developed those learning skills necessary to undertake further studies with a high degree of autonomy.

Source: Modification report of the Degree in Industrial Chemical Engineering (2020).

The subject analysed is mainly a practical one that aims to train students in the following:

- The production of process flow diagrams.
- Classification and description of industrial scale equipment.
- Conducting experiments and interpreting and analysing the data obtained on matter transfer, chemical reactions, and environmental technology.
- Carrying out group work.
- Written communication.

The development of this course has been based on the classical methodology of practical learning. The students have a pre-established practice script in which the steps to follow during the practice are indicated, the data to be obtained after its completion and a series of questions to answer based on the data obtained. The operating conditions in each of the practical exercises are pre-established and students do not have the possibility of varying any of the process parameters. The problem-based learning methodology was proposed in a new practice in this subject that allows the active participation in the process by the students, making them the protagonists of their own learning with the manipulation of most of the key parameters that had to do with the practice. Only two parameters were set: one for purely operational reasons; the other, in order to be able to compare results between groups. In this way, when students are confronted with a real case in which they have to provide a solution to a given problem and that solution depends solely on the work they do during the course of the class, all the competencies of the order CIN 351/2009 can be covered. Specifically, the use of the PBL methodology allows the development of the ability to solve problems with initiative, decision-making, critical reasoning and to communicate and transmit knowledge, skills and abilities in the field of Industrial Chemical Engineering, in addition to all the basic competencies.

2.2 Experimental installation

The experimental plant consisted of 6 pressure tubes containing nanofiltration and reverse osmosis membranes (3 nanofiltration and 3 reverse osmosis) installed as shown in Figure 1. The pressure pipes are not identified, so that the student cannot visually distinguish the membranes of each type. The system is fed with mains water, driven by two commercial “boost” pumps. It should be noted that mains water on the Tenerife Island is generally characterised by a high ion content. For the application of the pressure required, a needle valve located in the general process outlet stream was used. The system is set to a working pressure of 6 bar and operated in a closed circuit. The performance of the process is determined by two parameters: ion removal and water recovery. The first is calculated from experimentally measured electrical conductivity data in the product water (hereafter referred to as permeate) and in the feed. The second is obtained from the experimental determination of the overall permeate and reject flows. From these values, the percentage of process water recovery or recovery (ratio of product water flow obtained to feed flow) is determined.

Fig. 1. Experimental unit

The experimental installation allowed for the versatile and agile modification of the pipes, both to characterise the membranes individually and to test all the configurations proposed by the students.

2.3 Description of the learning methodology applied

The problem-based learning methodology was implemented in the subject described above by means of the resolution of an industrial problem by the students during a practical session lasting 2 hours. The total number of students enrolled in the subject was 25. Figure 2 shows the flow chart of the teaching methodology applied.

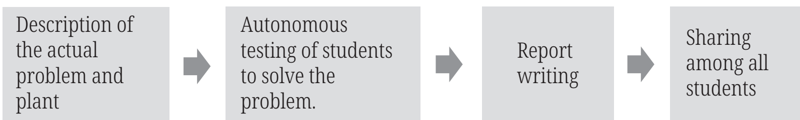

Fig. 2. Learning methodology

First, the students were tested on their prior knowledge to find out how well they had assimilated the theoretical concepts used in practice. The test consisted of 5 single-choice questions.

In the practical session, each group of three students was presented with a reverse osmosis and/or nanofiltration membrane installation already installed, the configuration of which did not allow them to obtain a product water that met the quality objectives already set by the lecturers (90% ion removal compared to the feed water).

After an orientation on the operation of the plant and a check that the students had the necessary background knowledge, they were first asked to determine the ion removal rate of the already installed configuration to know where they were starting from. Once the students found that the original process configuration did not meet the quality requirements, it was suggested that they analyse each of the membranes individually, as a starting point to come up with an alternative solution that would improve the product water performance, reach the quality target, and maximise water recovery in the process.

To reach the possible solutions, the students should select, according to their criteria, both the membranes to be used and the order of the membranes, analysing in each case the results obtained, and progressively orienting themselves towards the optimal configuration. On average, the working groups tested 4 configurations.

After recording the values obtained in the laboratory, the working group produced a report detailing the process followed, the identification of the membranes and the justification, based on experimentation and supported by theoretical knowledge, of the configurations chosen to arrive at the optimal solution, such as the phenomena that prevented certain tested configurations from not giving an acceptable result.

Finally, in a collective session, each of the working groups presented the configuration they considered optimal among those tested, justifying their decision in a reasoned manner. After presenting all the solutions, the students repeated the initial test to find out the degree of assimilation of the same concepts after carrying out the practice. The difference in the score of this test was used as an indicator of the effectiveness of this type of teaching methodology.

3 RESULTS AND DISCUSSION

3.1 Evaluation of acquired knowledge

The purpose of the practical course is not to provide new knowledge since this knowledge is developed in theoretical subjects of the syllabus of the Degree in Chemical Engineering at the University of La Laguna. The practical course aims to apply this knowledge and to transmit other competencies to the students. However, it was considered appropriate to assess the previous knowledge acquired by the students in a traditional theoretical class and the knowledge assimilated through the alternative system of problem-based learning.

The assessment of the knowledge acquired was developed by means of a multichoice test questionnaire with a single correct option where the student is asked simple questions on how they should modify operating conditions to achieve a desired objective. Figure 3 shows the percentage of correct answers to each of the questions before and after the laboratory practice. In the pre-questionnaire, the students' results were rather low, as the percentage of correct answers shows. In the first 4 questions, more than half of the students answered incorrectly, showing that they had not internalized basic knowledge from previous theoretical subjects. Once the laboratory practice had been carried out by means of problem-based learning, the results improved notably, with a high percentage of correct answers exceeding 50% in all cases.

The results highlight the importance of practical subjects as they help students to assimilate knowledge better by being able to understand the concepts taught in a theoretical way. Furthermore, the results show that the problem-based methodology allows students to transfer theoretical knowledge to practical cases and to interrelate concepts taught in different theoretical subjects in order to prepare students for their professional exercise. The concepts assimilated when students are confronted with a case study in which they have to propose a solution are internalised more deeply, allowing for greater assimilation because they are made to "think outside the box" [20]. Moreover, since it is a real problem where there is no single solution, or at least no obvious solution, it encourages critical analysis by students and collaborative learning where the solutions of classmates help to support global knowledge. In the development of the practice, critical debates were established between the members of the working group, allowing each of them to present their knowledge and reflections on the process to the rest of the group members in order to find an optimal solution to the problem posed. The pedagogical exercise carried out by the participants themselves allows them to assimilate and internalise the knowledge acquired.

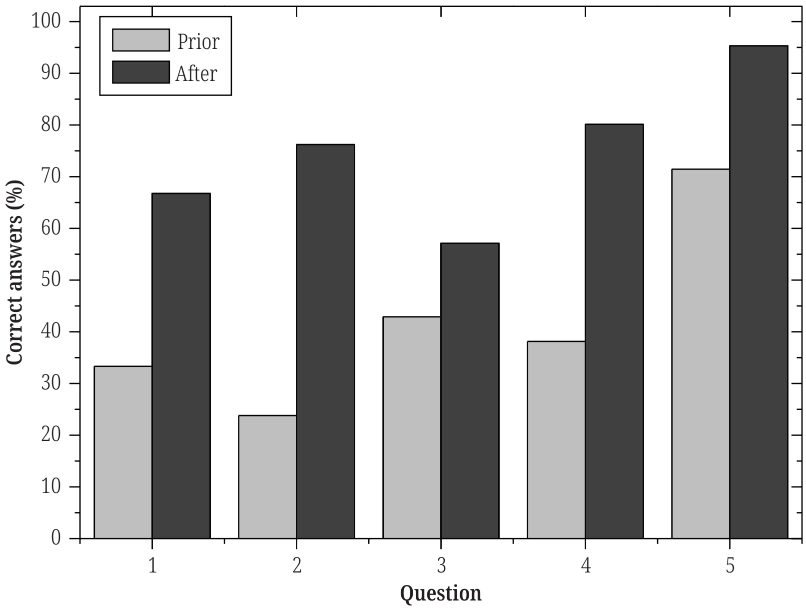

Fig. 3. Results of the test evaluation carried out prior to and after the practical sessions

3.2 Evaluation of acquired knowledge

The quantification of the skills acquisition by the students is not a simple task since many of them are not directly quantifiable. In order to evaluate the competencies, the students carried out a survey on their perception of the acquisition of competencies, in which they had to respond on a Likert scale of 1 to 5 (1 is not very satisfied and 5 is very satisfied). Table 2 summarizes the percentages of student responses to each of the questions. A fairly high degree of satisfaction was obtained for most of the questions, with an average of 4.5 out of 5 for all questions.

Table 2. Survey results

Question	% Answer According to Rating				
	1	2	3	4	5
The development of the internship has helped me to learn how to deal with a real case.			8	16	76
The material in the practice script was sufficient to solve the problem.	12		8	40	40
The sharing has helped me to understand the problem and to propose a solution.				24	72
I consider that for this type of practice it is better to do it in a group.				8	92
I consider it appropriate to use this type of methodology to learn by solving real cases.				24	76
I prefer this type of laboratory practice to more conventional ones.			4	20	76
The knowledge acquired in previous subjects has helped me to solve the initial questionnaire without any problems.	4	16	24	40	16
My knowledge in previous subjects has helped me to solve the problem solved.	4	12	28	40	16
This methodology has increased my motivation to carry out the practice.				20	80
The teaching staff involved has served as a guide for the resolution of the proposed problem.				24	76

The majority of students consider that the development of the internship has helped them to learn how to deal with a real case and that the shared session has helped them to understand the problem and propose an optimal solution. Reflecting that, according to the opinion of the students, the development of the internship has allowed them to acquire methods that provide them with versatility to adapt to new situations, bringing them closer to their professional practice. The results are consistent with what was described in the previous section regarding "thinking outside the box" and the internalisation of knowledge when presenting their ideas and findings.

It is remarkable how some students, around 20%, indicate that the theoretical knowledge acquired in previous subjects has not made it easier for them to solve the proposed case or the previous questionnaire. This is one of the main challenges of university education today, as some students memorise theoretical concepts without being able to transfer these concepts to their professional practice. A percentage of students (12%) considered that the practice guide was not sufficient to solve the problem, when it was a brief summary of the basic concepts. The students expected a detailed guide to help them solve the proposed case, as is done in traditional laboratory practical. However, providing such information would have slowed down the critical thinking and self-learning process as reflected in the results in Figure 3.

One of the objectives set in the achievement of the laboratory practice is the development of the students' group work and their collective self-learning. The results of the survey show that students value positively the development of the practice in working groups and their preference for this type of laboratory practice as opposed to traditional systems based on following a written procedure and collecting data to produce a final report. The problem-based methodology applied in the laboratory practice has allowed them to develop decision-making skills with critical reasoning, encouraging creativity to reach a solution that they had to communicate and transmit to their classmates.

The proposed methodology allowed students to acquire skills in the design and management of experimentation procedures, as they themselves had to propose the methodology to be followed within a given time. Obviously, the teacher had to channel these ideas and act as a guide, this being a key role in the process. The students valued very positively the work of the teacher in the development of the practice.

In summary, the development of this new methodology enables students to acquire and internalize practically all the competencies described in the CIN Order 351/2009, which are summarised in Table 1.

3.3 Student evaluation of the methodology used

Problem-based methodology is a powerful pedagogical tool that teachers can use for the acquisition of new skills [2]. However, it is appropriate to know the students' opinion about this methodology since it represents a break from the traditional systems that are highly implemented in educational systems. In order to evaluate the proposed methodology, the students completed a survey in which they had to rate different aspects of the development of the practice on a Likert scale from 1 to 5. The results are shown in Figure 4.

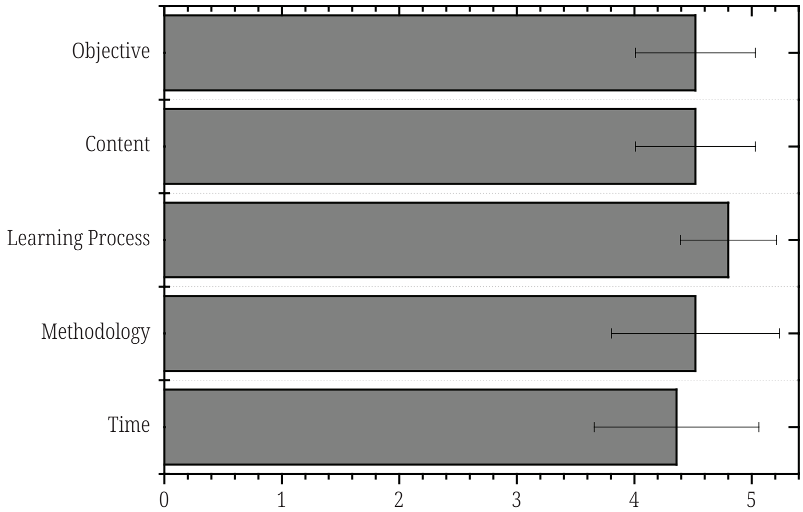

Fig. 4. Student evaluation of the methodology applied

Students rate the proposed methodology very positively, giving it an average score of 4.47 out of 5. The results reveal that students prefer this type of methodology to traditional systems when carrying out laboratory practicals.

In the same survey, the students could add comments regarding their impressions of the proposed methodology. The results mostly value positively the group work and the possibility of facing a real case that has allowed them to know the degree of assimilation of concepts acquired during their learning stage. Furthermore, it is emphasised that the system seems to them to be novel and highly dynamic, which generates a high level of motivation. It should also be noted that the students were unaware of the Problem-Based Learning methodology. In order to analyse the students' impression of the new methodology, they were asked to choose from a total of 8 concepts/adjectives (positive and negative) those with which they would qualify the methodology used in practice. Figure 5 shows the number of times students chose each of them.

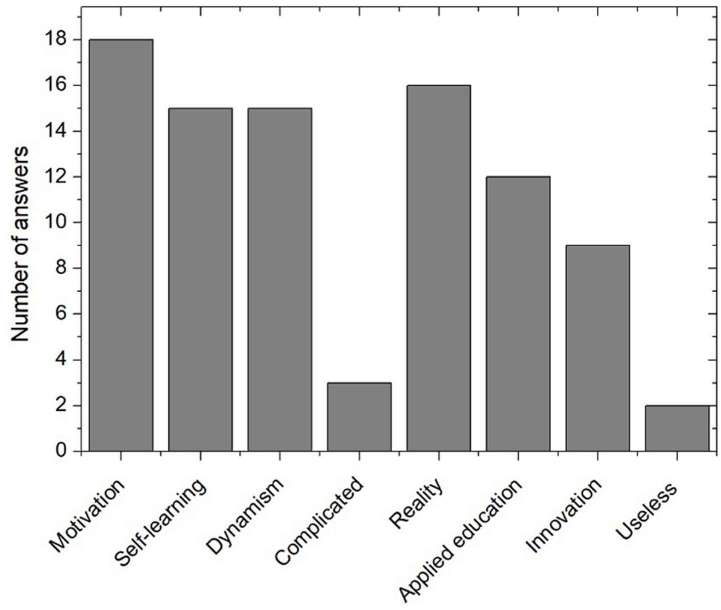

Fig. 5. Adjectives/concepts proposed for the description of the methodology followed according to the students' vision

"Motivation" is the concept most frequently chosen by students, followed by "Realism". "Self-learning", "Dynamism", "Applied teaching" and "Innovative" also stand out. The adjectives "Complicated" and "Useless" were the least chosen. These results show that the pupils consider this methodology to be clearly positive, enabling them to achieve self-learning in a motivating and dynamic way.

4 CONCLUSIONS

The manuscript evaluates the methodology of problem-based learning in the development of a laboratory practice in the last year of Industrial Chemical Engineering. The results show that this methodology improves the acquisition and internalisation of theoretical knowledge and its applicability to the resolution of real problems in the case of fourth-year students of the Degree in Industrial Chemical Engineering at the University of La Laguna. In addition, the proposed learning system in which students were faced with a real problem, without an obvious solution, encouraged critical analysis by the students and collective learning, allowing them to acquire knowledge in a more profound way. The students' assessment of this methodology is positive, and they even propose that it should be implemented in the rest of the practical subjects in the current degree program, as they consider it to be a way of encouraging student motivation and interest.

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6 REFERENCES

[1] F. Vega and B. Navarrete, "Professional design of chemical plants based on problem-based learning on a pilot plant," *Education for Chemical Engineers*, vol. 26, pp. 30–34, 2019, https://doi.org/10.1016/j.ece.2018.08.001

[2] R. Vaez Ghaemi and G. Potvin, "Experimenting with labs: Practical and pedagogical considerations for the integration of problem-based lab instruction in chemical engineering," *Canadian Journal of Chemical Engineering*, vol. 99, no. 10, pp. 2163–2172, 2021, https://doi.org/10.1002/cjce.24136

[3] Y. Hu and C. Li, "Implementing a multidimensional education approach combining problem-based learning and conceive-design-implement-operate in a third-year undergraduate chemical engineering course," *J Chem Educ*, vol. 97, no. 7, pp. 1874–1886, 2020, https://doi.org/10.1021/acs.jchemed.9b00848

[4] J. Uziak and V. P. Kommula, "Application of problem-based learning in mechanics of machines course," *International Journal of Engineering Pedagogy*, vol. 9, no. 1, pp. 68–83, 2019, https://doi.org/10.3991/ijep.v9i1.9673

[5] W. Chen, U. Shah, and C. Brechtelsbauer, "The discovery laboratory – A student-centred experiential learning practical: Part I – Overview," *Education for Chemical Engineers*, vol. 17, pp. 44–53, 2016, https://doi.org/10.1016/j.ece.2016.07.005

[6] H. Ju, I. Choi, B. Doo Rhee, and J. Tae-Lee, "Challenges experienced by Korean medical students and tutors during problem-based learning: A cultural perspective," *Interdisciplinary Journal of Problem-based Learning*, vol. 10, no. 1, 2016, https://doi.org/10.7771/1541-5015.1565

[7] J. R. Savery, "Overview of problem-based learning: Definitions and distinctions," *Interdisciplinary Journal of Problem-Based Learning*, vol. 1, no. 1, 2006, https://doi.org/10.7771/1541-5015.1002

[8] A. M. Ruiz-Ortega, J. J. Gallardo-Rodríguez, E. Navarro-López, and M. del C. Cerón-García, "Project-led-education experience as a partial strategy in first years of engineering courses," *Education for Chemical Engineers*, vol. 29, pp. 1–8, 2019, https://doi.org/10.1016/j.ece.2019.05.004

[9] R. Wood, A. McGlashan, C. B. Moon, and W. Y. Kim, "Engineering education in an integrated setting," *International Journal of Engineering Pedagogy*, vol. 8, no. 3, pp. 17–27, 2018, https://doi.org/10.3991/ijep.v8i3.7857

[10] J. Castelan and R. D. Bard, "Promoting PBL through an active learning model and the use of rapid prototyping resources," *International Journal of Engineering Pedagogy*, vol. 8, no. 4, pp. 131–142, 2018, https://online-journals.org/index.php/i-jep/article/view/8281/5013

[11] B. D. Jones, M. K. Byrnes, and M. W. Jones, "Validation of the MUSIC model of academic motivation inventory: Evidence for use with veterinary medicine students," *Front Vet Sci*, vol. 6, 2019, https://doi.org/10.3389/fvets.2019.00011

[12] L. A. Jesper, J. F. D. Nielsen, and C. Zhou, "Motivating students to develop satellites in problem and project-based learning (PBL) environment," *International Journal of Engineering Pedagogy (iJEP)*, vol. 3, no. 3, p. 11, 2013, https://doi.org/10.3991/ijep.v3i3.2529

[13] S. Fernandes, M. A. Flores, and R. M. Lima, "Students' views of assessment in project-led engineering education: Findings from a case study in Portugal," *Assess Eval High Educ*, vol. 37, no. 2, pp. 163–178, 2012, https://doi.org/10.1080/02602938.2010.515015

[14] S. Fernandes, D. Mesquita, M. A. Flores, and R. M. Lima, "Engaging students in learning: Findings from a study of project-led education," *European Journal of Engineering Education*, vol. 39, no. 1, pp. 55–67, 2014, https://doi.org/10.1080/03043797.2013.833170

[15] R. M. Lima, D. Mesquita, and L. Coelho, "Five years of project-based learning training experiences in higher education institutions in Brazil," in *6th International Research Symposium on PBL (IRSPBL' 2017)*, 2017, pp. 470–479.

[16] I. Syamsuddin, "Problem based learning on cloud economics analysis using open source simulation," *International Journal of Online Engineering*, vol. 12, no. 6, pp. 4–9, 2016, https://doi.org/10.3991/ijoe.v12i06.5147
[17] Darmaji *et al.*, "E-module based problem solving in basic physics practicum for science process skills," *International journal of online and biomedical engineering*, vol. 15, no. 15, pp. 4–17, 2019, https://doi.org/10.3991/ijoe.v15i15.10942
[18] T. T. D. Susanto, P. B. Dwiyanti, A. Marini, J. Sagita, D. Safitri, and E. Soraya, "E-book with problem based learning to improve student critical thinking in science learning at elementary school," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 20, pp. 4–17, 2022, https://doi.org/10.3991/ijim.v16i20.32951
[19] M. (John) Zhang, C. Newton, J. Grove, M. Pritzker, and M. Ioannidis, "Design and assessment of a hybrid chemical engineering laboratory course with the incorporation of student-centred experiential learning," *Education for Chemical Engineers*, vol. 30, pp. 1–8, 2020, https://doi.org/10.1016/j.ece.2019.09.003
[20] A. T. Harris and S. Briscoe-Andrews, "Development of a problem-based learning elective in 'green engineering,'" *Education for Chemical Engineers*, vol. 3, no. 1, 2008, https://doi.org/10.1016/j.ece.2007.12.001

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