The Effect of Integrating Interactive Simulations on the Development of Students' Motivation, Engagement, Interaction and School Results

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Abstract—The concept of chemical bonding and related concepts are essential topics for the fundamental understanding of chemistry courses by secondary school students. Because of the abstraction aspect, students find it difficult to understand this topic. The aim of this study is to improve students' motivation, engagement, interaction and school results by integrating interactive simulations into the teaching-learning process of chemical bonding concepts. The study was conducted in a secondary school in the Kingdom of Morocco, with a sample of 56 students in the qualifying secondary education cycle. The sample was divided into an experimental group and a control group. The experimental group is taught using more molecular models PhET simulations, while the control group follows the traditional teaching method. Using a quantitative research method with a pre- and post-test design, and an observation grid measuring students' motivation, engagement and interaction before and after the integration of interactive simulations. The data were then analysed using the IBM SPSS 25 program. The results showed that students in the experimental group working with PhET interactive simulations scored significantly higher ($p<.01$) than students in the control group after the post-test, thus the study showed that there is a positive correlation between students' motivation, engagement, and interaction and their school results during instruction using PhET computer simulations combined with molecular models. Therefore, the results of this study suggest that the teaching-learning of chemistry topics related to chemical bonding can be enhanced using PhET interactive simulations combined with molecular models. This research highlights the usefulness of integrating interactive simulations into the chemistry teaching-learning process.

Keywords—interactive simulations, motivation, interaction, engagement, school results, students, chemical bonding

1 Introduction

Chemical bonding is a fundamental topic in the chemistry curriculum, underpinning most of the topics covered in chemistry courses in secondary and post-secondary education [1,2]. It is necessary for students to understand the meaning of chemical bonding concepts in order to understand other chemistry topics such as chemical reactions, chemical reactivity, structure of matter, change of state, physical and chemical change [3]. However, previous studies have shown that students have difficulties in understanding the concept of chemical bonding and related concepts (geometry of molecules, the octet rule...) and have various misconceptions about it, which are directly due to the theoretical and abstract nature of the concepts [4–7]. This can influence the learning of chemistry in all curricula if not corrected.

Studies conducted by several researchers show that the integration of computer simulations, which are also called 'computer representations of situations', 'representations of real phenomena' or 'hypotheticals', is an environment that provides a dynamic learning experience, interactive and visualised learning experience [8] in the classroom and that they can be used as a very rich tool in the process of teaching-learning science and chemistry in particular as a general teaching aid that complements classical teaching methods, and one of the most powerful means used to overcome learners' difficulties with concepts related to chemical bonding.

The Physics Education Technology (PhET) interactive simulations is a platform developed by the University of Colorado at Boulder, which includes several simulations that are freely available for open use. It can be accessed online via the URL or via an executable to be installed. Each simulation is accompanied by several additional tools that immerse students in a guided learning activity [9]. PhET was created by a group of content experts, educators, interface design experts and professional software developers.

PhET interactive simulations offer many advantages that attract teachers to integrate them into chemistry learning in general and especially during the teaching of chemical bonding parts. First of all, the simulations can be used as a complementary tool to the laboratory as in the case of our study where the use of molecular models combined with PhET simulations. Secondly, simulations remain a suitable tool for teachers to show learners how to form chemical bonds between atoms and offer students the possibility to explore and manipulate things that would otherwise be impossible on the blackboard or in textbooks, such as visualising molecules in three dimensions, and it helps to facilitate the understanding of abstract and difficult concepts and reduce students' misconceptions [10–11].

In addition, they allow students to visualise entities at the atomic scale and describe behaviours at the sub-microscopic level of which they were not previously aware [12–13]. The use of this simulation also allows students to understand and relate both chemical systems and what is happening at the sub-microscopic level from the dynamic visualisation [14–17] and helps students to overcome learning difficulties and improve academic performance [18]. Interactive simulations help learners to repeat experimental simulations several times and subsequently assist in the realisation of scientific phenomenon [19], Simulations help learners to grasp real world data through multiple representations [20–22]. In addition, simulations give students the opportunity to visualise and experience things that would be impossible to handle in the laboratory, such as manipulating an object [23]. It remains to be said that simulations are increasingly effective if they are integrated at the right time and in an appropriate activity [24].

On the other hand, the use of PhET interactive simulations increases learners' interest and motivation. PhET interactive simulation is a scientific approach designed to improve problem-solving skills [25]. Similarly, other researchers have shown that simulation-based learning has a positive effect on learning and is an effective tool to facilitate the learning of complex skills [26]. They also reported that the use of PhET interactive simulation to enhance scientific creativity based on motivation theory, cognitive psychology theory and social constructivist learning theory [23].

We also point out that the use of interactive simulations in the teaching-learning process increases student engagement and improves questioning and reasoning skills [27]. Another potential benefit of interactive simulations is the enhancement of motivation and creativity and the creation of a stimulating learning environment improves teachers' instructions and facilitates learners' engagement [28].

Therefore, the aim of this study is to improve students' motivation, engagement and interactivity and their academic performance from the integration of interactive simulations in the teaching-learning process of chemical bonding concepts. In this regard, the research questions that this study intends to answer are: To what extent could the integration of PhET interactive simulations improve students' understanding of concepts related to chemical bonding, and can students' motivation, engagement and interactivity be considered to lead them to achieve outstanding academic results through interactive simulations?

2 Methodology

2.1 Characteristics of the sample

The following table (Table 1) presents the choice of the sample for this study. We opted for a sample of 56 students in qualifying secondary education (10th grade) in a public secondary school in the provincial administration of Chefchaouen in the Kingdom of Morocco. The sample is randomly distributed and sharing more or less similar characteristics, it is divided into two groups, one group is considered as the experimental group of 28 students of which 78.57% are girls and 21.42% are boys and the other as the control group of 28 students of which 75% are girls and 25% are boys (Table 1).

Table 1. Distribution of participants by gender and method used

Group	Total	Gender			
		Boys		Girls	
Experimental group (EG)	28	06	21,42%	22	78,57%
Control group (CG)	28	07	25%	21	75%
Total	56	13	23,21%	43	76,78%

2.2 Conduct of the research

During the experimentation of this study, we opted for two learning environments. One learning environment with the integration of PhET interactive simulations and another without the integration of simulations. We chose the course "Geometry of some molecules" as the learning sequence provided to both groups during the experimentation. The course sessions take place in the physical science laboratories during three weeks. In addition, the experimental procedure consisted of three different phases.

Phase 1: Prior to the intervention, a pre-test of the chemistry knowledge test was administered to the experimental group (n=28) and the control group (n=28) in the first session.

Phase 2: The interventions were introduced to teach the topics related to chemical bonding to the experimental group using the interactive PhET simulation combined with molecular models (Figures 1 and 2). In contrast, students in the control group learned similar topics using the molecular model-based method only (Figure 2).

Phase 3: At the end of the third week, the post-test was administered for both groups.

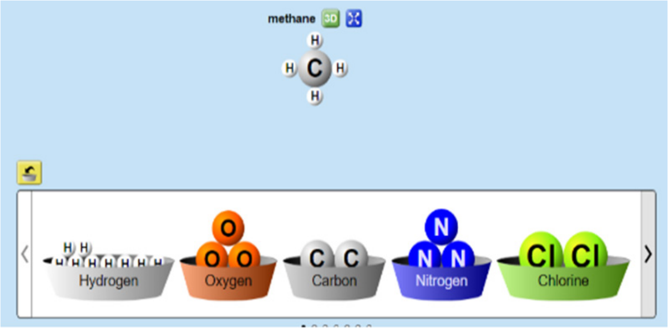

Fig. 1. A screenshot of an interactive PhET simulation (Build a Molecule)

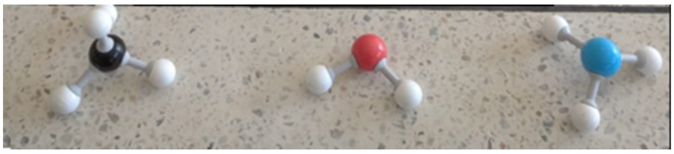

Fig. 2. An example of the Molecule Models used during the session

2.3 Data collection tools

In order to collect relevant data to this research, the following data collection tools were used:

- Pre-test: This test ensures that the groups are homogeneous at the outset. It measures background knowledge and the degree of mastery of chemistry prerequisites. Students from both groups took a pre-test. This test consisted of 10 multiple-choice questions, where students had to choose one correct answer from four possibilities and for each correct answer the student received two points. The total score of the test is 20 points.
- Post-test: This test is conducted to determine the impact of the integration of the interactive simulations on the understanding of the concepts related to chemical

bonding and to compare the students' responses between the two groups. The post-test contains multiple-choice questions (MCQs), the purpose of which is to measure the students' achievement of the learning objectives.

- Observation grid: This direct student observation grid aims to monitor the attitudes of students in the experimental group before and after the integration of the interactive simulations. The grid covers 3 dimensions: motivation, engagement, and interactions between learners and with the teacher.

In this study, we consider the following study variables:

- Students' learning outcomes, motivation, engagement and interactions are considered the dependent variables.
- The teaching method (with or without integration of interactive simulations) is considered the independent variable.

2.4 Data analysis tool

The data collected from the experimental study were coded and analysed using SPSS version 25 descriptive and inferential statistical software. Data were analysed in terms of mean scores and standard deviations. All results were interpreted at $p < 0.05$.

The following figure (Figure 3) presents a summary diagram of the research methodology during this study:

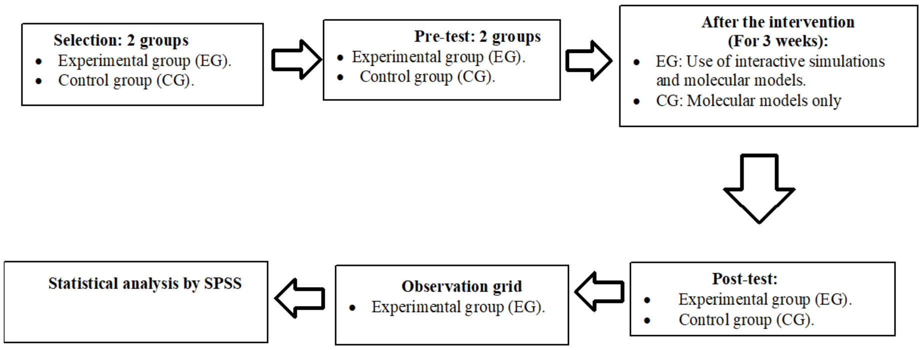

Fig. 3. A diagram of the researchers' exploratory research design in this study

3 Results

3.1 Results' comparison of the experimental and control groups

Table 2 presents the comparison of the mean scores of the diagnostic assessment (pre-test) for the two groups. The results show that there is a small difference in mean of about 0.57 between the control group (CG) and the experimental group (EG), these results indicate that the two groups are similar (CG: 9.71±3.720; EG: 9.14±3.194).

Table 2. Descriptive statistics of the average score for the two groups (pre-test phase)

Group	N	Minimum	Maximum	Mean Scores	Standard Deviation	Mean Standard Error
Control group (CG)	28	2	18	9,71	3,720	0,703
Experimental group (EG)	28	4	16	9,14	3,194	0,604

The following table (Table 3) shows the results of the normality tests using the Shapiro-Wilk test for both groups, we obtained a significance value of 0.609 for the control group (CG) and 0.099 for the experimental group (EG), both values are above the significance level of p-value 0.05, which allows us to conclude that the normality of the data is normal for both groups.

Table 3. Normality tests of pre-test data

Group	Shapiro-Wilk		
	Statistics	ddl	Sig.
Control group (CG)	0,971	28	0,609
Experimental group (EG)	0,938	28	0,099

According to Table 4, the results of Levene's test for homogeneity of variance indicate that the population of variance is homogeneous with F-value=0.314 and p=0.578>0.05. Thus, the results of the t-test show that there is no statistically significant difference between the mean scores obtained in the pre-test between the control and experimental groups (t=0.617, df=54, p=0.540>0.05).

Table 4. Independent samples t-test for both groups (pre-test)

	Levene's Test for Equality of Variances		T-Test for Equality of Means						
	F	Sig.	t	ddl	Sig. (Two-Tailed)	Mean Difference	Standard Error Difference	Confidence Interval of the Difference at 95%	
								Lower	Upper
Assumption of equal variances	0,314	0,578	0,617	54	0,540	0,571	0,927	–1,286	2,429
Unequal variances assumption			0,617	52,790	0,540	0,571	0,927	–1,287	2,430

Table 5 presents a comparison of the mean post-test scores for the two groups, the results show that the mean obtained m1=16.79 of the experimental group (EG) is higher than that of the control group (CG) m2=12.50 and the standard deviation of the score of the two groups are 4.978 and 2.948 respectively. The difference in the mean between the two groups is approximately 4.29.

Table 5. Descriptive statistics of the average score for the two groups (post-test phase)

Group	N	Minimum	Maximum	Mean Scores	Standard Deviation	Mean Standard Error
Control group (CG)	28	2	20	12,50	4,978	0,941
Experimental group (EG)	28	8	20	16,79	2,948	0,557

Table 6 shows the results of the Shapiro-Wilk normality test, the significance value of the data of the experimental group is 0.004 which is less than the p-value = 0.05 so the distribution is not normalized, while the value of the control group is 0.193 which is higher than the significant value of 0.05 so the distribution is normalized.

Since one of the groups does not have a normal distribution, then the next method will be using a non-parametric test which is the Mann-Whitney test to compare the means of two independent samples.

Table 6. Pre-test normality tests

Group	Shapiro-Wilk		
	Statistics	ddl	Sig.
Control group (CG)	0,950	28	0,193
Experimental group (EG)	0,880	28	0,004

The following table (Table 7) presents the results of the Mann-Whitney test. The results indicate that there is a statistically significant difference between the two groups as the asymptotic sig. value (two-sided test) is 0.001 less than 0.01. Therefore, there is a highly significant difference in favour of the experimental group in acquiring knowledge about chemical bonding through PhET simulation.

Table 7. Mann-Whitney test of independent samples for the two study groups (post-test)

Total N	56
Mann-Whitney U	600,000
Wilcoxon's W	1006,000
Test statistic	600,000
Standard error	60,293
Normalised test statistic	3,450
Asymptotic sig. (two-sided test)	0,001

After the experimentation phase, the students took a formative evaluation to assess the student's progress towards the pedagogical objectives after the integration of the interactive simulations. The control group (CG) obtained an average score of 15.23 (/20), while the experimental group (EG) obtained an average score of 17.54 (Table 8).

Table 8. Weighted averages during a formative evaluation

Group	N	Average Score
Control group (CG)	28	15,23
Experimental group (EG)	28	17,54

3.2 The development of student's motivation, engagement and interaction towards the integration of interactive simulations

Based on the observations made on the experimental group during the two phases before and after the integration of the simulation using an observation grid. Table 9 shows the descriptive results of the observations of students' motivation, engagement and interaction before and after the integration of the interactive simulations. Overall, the averages of students' motivation, engagement and interaction in the teaching-learning process after the integration of the interactive simulations are quite higher than before integrating the simulations.

Table 9. Number of occurrences of indicators of motivation, engagement, interaction of students in the experimental group before and after the integration of interactive simulations

Dimension	Indicators	Before Simulation		After Simulation	
		N	Proportion	N	Proportion
Motivation	Item1	14	50%	21	75%
	Item2	6	21,42%	11	39,28%
	Item3	10	35,71%	18	64,28%
	Item4	12	42,85%	19	67,85%
	Average		37,49%		61,60%
Engagement	Item1	10	35,71%	13	46,42%
	Item2	12	42,85%	23	82,14
	Item3	14	50%	15	53,57
	Item4	12	42,85%	20	71,42%
	Average		42,85%		63,38%
Interaction	Item1	14	50%	21	75%
	Item2	12	42,85%	24	85,71%
	Item3	13	46,42%	18	64,28%
	Average		46,42%		74,99%

For the dimension of student motivation: The results of the above table (Table 9) show that the rate of motivated students in the teaching-learning process after the integration of PhET interactive simulations is higher (61.60%) than before the integration of PhET (37.49%).On the other hand, we calculated the evolution between the two periods by the formula =(%.after-%.before)/(%.before)×100, and we found that there was an increase in the rate of student motivation of 64.31%.

For the dimension of student engagement: The results show that the rate of student engagement in the teaching-learning process after the integration of PhET interactive simulations is higher (63.38%) than before the integration of PhET (42.85%) (Table 10). On the other hand, we calculated the evolution between the two periods and found an increase in the students' engagement rate of 47.91%.

For the dimension of student interaction: The results show that the rate of student interaction between peers and with the teacher during the teaching-learning process after the integration of PhET interactive simulations is higher (74.99%) than before the integration of PhET (46.42%). On the other hand, we calculated the evolution between the two periods and found an increase in the students' interaction rate of 61.54%.

Table 10 presents the results of the Pearson test correlation between students' school results and students' motivation (r=.953, p=.000), engagement (r=.960, p=.000) and interaction (r=.854, p=.000). The results show that all three correlations of school results with motivation, engagement and interaction are highly significant.

Table 10. The correlation between academic performance and students' motivation, engagement and interaction

		School Results	**Motivation**	**Engagement**	**Interaction**
School results	Pearson correlation	1	,953**	,960**	,854**
	Sig. (two-tailed)		,000	,000	,000
	N	28	28	28	28
Motivation	Pearson correlation		1	,946**	,843**
	Sig. (two-tailed)			,000	,000
	N		28	28	28
Engagement	Pearson correlation			1	,823**
	Sig. (two-tailed)				,000
	N			28	28
Interaction	Pearson correlation				1
	Sig. (two-tailed)				
	N				28

Note: **Correlation is significant at the 0.01 level (two-tailed).

4 Discussion

Firstly, we recall that the aim of our research is to improve students' motivation, engagement, interactivity and school results through the integration of interactive simulations into the teaching-learning process of concepts related to chemical bonding.

We will discuss the results obtained in the light of our aim, and in the light of previous research.

The results show that there is no statistically significant difference between the degree of mastery of the knowledge acquired by the two groups, implying that both groups were similar and had the same level of prior understanding of the chemistry course at the beginning. These results were predictable because both groups had received the same curriculum since the beginning of the current season. The consistency of the results of the two groups is a good starting point for determining whether the method used will have an effect on a given group. And whether the experimental group will achieve higher academic results than the control group at post-test.

However, from the post-test results of both groups it can be concluded that there is a statistically significant difference between the groups in favour of the experimental group. This result indicates that the students trained with the interactive simulations performed better and improved their skills. These results have been confirmed by some works that explain that the effect of simulations simulate reality and help students to understand difficult and abstract concepts, as well as make the process of teaching learning chemistry timelier and more user-friendly [12, 29–30].

Furthermore, the results showed that the use of interactive simulations allow secondary school students to better understand and interpret concepts related to chemical bonding, thus this study indicates that simulations are effective in teaching new scientific content to secondary school students, which has been confirmed by other similar studies such as Adams' study [31], consequently PhET interactive simulations have positive effects on students in learning chemistry in general [29, 32–35]. Furthermore, interactive simulations allow visualization at the sub-microscopic level and therefore help learners who encounter difficulties in understanding abstract concepts and concepts at the atomic scale that require visualization, and also reduce the formation of common misconceptions related to the subject as in the case of our study, these results are in line with the findings of Kozma and Russell [36].

On the other hand, investigations carried out in the same sense have shown that the presence of interactive simulations brings added value by allowing to propose activities that are not possible with classical teaching, for example turning the molecules and seeing them from different angles and seeing the molecules animated in three dimensions (3D) as in the case of our study, this finding is affirmed by several researchers [34, 36–39].

The results obtained in this research showed a considerable improvement in some indicators such as motivation, engagement and interaction of the students in the experimental group who benefited from the integration of interactive simulations in the teaching-learning process compared to the classical method. We noticed that the students in the experimental group were more motivated, engaged and interacted during the integration of the interactive simulations. These results are supported by [34, 40, 41–42].

In between, we observed high motivation in students after using PhET simulations, thus simulations are effective tools to increase motivation, this claim is supported by several of the researchers [9, 42–43, 44–49], Furthermore, the results of this research showed that simulations can increase students' engagement in the learning process. These results are consistent with the findings of [28, 31, 32, 43]. On the other hand, this study has shown that PhET simulation can integrate students into a learning environment. Thus, we can confirm that the adoption of PhET simulations improves the interactive exchange between learners [40, 42].

In conclusion, the integration of interactive simulations with molecular models offers students the opportunity to:

- Manipulate models of atoms and molecules.
- Visually inspect different elements within molecules (the bond angle, the spatial arrangement of atoms in molecules).
- Decode symbolic information (the blue sphere representing a nitrogen atom);
- Making a 3D animated representation is better than the 2D representation for understanding the geometry of molecules (manipulating models in space);
- Offer students to experience chemistry at the macroscopic, submicroscopic and symbolic levels.

Nevertheless, the present study has identified some limitations that deserve to be mentioned:

- This experiment was conducted with only two groups of students from one school.
- The experiment focused on a limited sample (56 students).
- The study was limited to the relative concepts of chemical bonding in chemistry.
- The use of an invalid observation grid which may impact on the results obtained.

5 Conclusion

This research has demonstrated the impact of integrating interactive molecular model simulations on students' understanding and academic performance during chemistry instruction, particularly for concepts related to chemical bonding. We found that the combination of interactive simulations and molecular models allows students to provide a valuable exploratory learning environment where they can learn different chemistry concepts.

In addition, the study provided supporting evidence for the integration of interactive simulations into the teaching-learning process in chemistry. The results of the present study reveal a significant positive impact of the integration of simulations with molecular models on students' understanding. Our analysis indicates that there are significant differences in students' achievement of concepts related to chemical bonding, simulations significantly improve chemistry skills, the results also show that simulation improves learning achievement as well as simulations motivate students during the lesson, increase interaction between them and increase students' engagement in the learning process. This impressive impact underlines the importance of simulations for learning.

Based on the results of this research, we concluded that the use of interactive simulations in chemistry teaching could be an effective pedagogical tool to improve the teaching-learning process compared to the traditional method, enable students to master concepts related to chemical bonding and facilitate the learning of complex and abstract concepts. This reality challenges teachers to develop innovative teaching strategies using interactive simulations.

We also hope that sharing the results of our research can trigger further studies on the impact of interactive simulations, to consolidate our results and make them more reliable, many samples should be used in future work followed by interviews with participants, it would be advantageous to conduct similar research with other concepts in chemistry and in different disciplines in order to better know their strengths and weaknesses, as well as to determine the best ways to integrate these pedagogical tools.

Our research can also encourage science and chemistry teachers in particular to use interactive simulations in their teaching practices, as PhET simulations can help teachers to explain chemical bonding concepts well. These simulations are beneficial for teachers when the concepts taught in chemistry are abstract and at the atomic scale as in the case of our study, as they rather attract students' attention, helping students to understand the scientific concepts effectively. In addition, simulation can also improve student motivation, engagement and interaction.

6 References

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