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# Assessing students' learning of abstract mathematical concepts in a blended learning environment enhanced with a web-based virtual laboratory

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**Abstract**

The purpose of this study was to assess fifth-grade students' learning of abstract mathematical concepts in a blended learning environment enhanced with a web-based virtual laboratory. The "PhET" simulations site was taken as a web-based tool since it introduces a research-based mathematics interactive simulation. The study aimed to identify the extent of differences in academic progress between the experimental group taught about "Fractions" through a flexible blended learning pedagogical model, and the control group taught the same concepts through the conventional method. Thirty students were targeted and randomly selected from a private school in Muscat. To answer the research questions, both the control and experimental groups were pre-post tested on learning the targeted abstract mathematical concepts. The results showed that there is a clear positive effect on raising the level of achievement of students in abstract mathematical concepts in favor of the experimental group. Also, the experimental group were interviewed to gain more understanding about their perceptions regarding the method used in learning abstract mathematical concepts. Students were found to highly favor using the simulation website.

**KEYWORDS:** Abstract Mathematical Concepts, Achievement, Blended Learning, Virtual Laboratory, Students' Perceptions.

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## 1. Introduction

Technological innovations nowadays include the advent of many web tools, which are convenient, easy to use and common for people in society. Being easily available and dominant in everyday life practices, these tools have become widely used at different times and places. They are also economic reducing both effort and time. According to Alket (2017), vast amounts of web-applications are increasingly accessed daily. This is evidence of the increasing use of various applications and web tools to meet the needs of beneficiaries.

The educational field, of course, is a fertile soil for employing and exploiting such technological innovations. As far as the educational system in the Sultanate of Oman is concerned, it is dominated by the traditional approach in different educational settings with some successful experiences, which have been experimented in some schools – both private and governmental. Undoubtedly, employing such innovations will increase students' understanding of abstract educational content and facilitate the delivery of knowledge to students in less time and effort. As web-based applications or tools, simulation environments are considered important for supporting and reinforcing different types and modes of learning, such as direct learning and self-learning, where learners can interact with the presented instructional content (Reese, 2020). Also, they can support distance learning, and increase accessibility for students with different learning styles and needs (Aboraya & Elkot, 2020, Elkot, 2019; Heradio et al., 2016).

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Therefore, many countries, including the Sultanate of Oman, have paid attention to contemporary technological innovations, which have a profound impact on the delivery of instructional content when modern teaching methods and varied instructional strategies/techniques are used. In this regard, Muhtadi, Kartasasmita, and Prahmana (2017) indicated the need to employ technology-rich learning environment in teaching mathematics. This will help students conceptualize and develop better understanding of mathematics.

Simulation is a modern teaching strategy, method, or style where the learner goes through direct experience to reflect, and eventually develop a judgment on what he/she has learned towards the end of the learning process. It provides an appropriate environment for carrying out activities, exercises, and conducting various experiments. In this respect, the researcher sought to assess students' learning of abstract mathematical concepts within a suitable pedagogical design based on employing and using simulation websites and selected the application of the "PhET" simulations site (PhET, 2020) as an example to measure the achievement level of the learners in teaching the fractions concepts. Also, the researcher sought to investigate the students' perceptions regarding the method used in learning.

Thus, the main research problem is represented in answering the following questions:

- What is the impact of employing a blended learning environment enhanced with web-based virtual laboratory on raising fifth-grade students' achievement in mathematics?
- What are the students' perceptions regarding the method used in learning abstract mathematical concepts?

## 2. Literature review

Recently, interest in e-learning and the delivery of varied electronic content has increased with the goal of achieving more effective and meaningful learning. Math teachers are encouraged to integrate computer technology in their teaching (Findley, Whitacre, Schellinger, & Hensberry, 2019). The use of software in teaching mathematics helps to overcome many problems experienced by learners and teachers: e.g. the problems of keeping information for a longer period; simplifying the knowledge received by the learner; and the problem of finding suitable and logical solutions (Al-Hazimi, 2017). Such software allows the freedom to experiment and repeat concepts learnt without fear of error or embarrassment (Muhammadi, 2015). In addition, many studies, indicate the importance of employing educational software in teaching mathematics (Miranda-Palma, Canche-Euán, & Llanes-Castro, 2015; Zengin & Tatar, 2017).

In view of the above, the researcher believes that most studies have concluded that the use of various electronic programs, whether connected directly to the World Wide Web or as independent software, has a significant impact on raising the achievement level in mathematics. The design of such software is value-added when developed and used based on related literature, theories, and scientific foundations of educational design (Muhammadi, 2015).

The studies that dealt with the virtual laboratories (labs), or simulations laboratories, assured their significant impact on the consolidation of knowledge and retention in the learners' minds for a longer time. Virtual labs can be described as a kind of e-learning that provides what other kinds cannot (Sarhan, 2016). They are virtual learning environment that exploits the computer affordances and facilities in the digital laboratory itself. Results show that using virtual laboratories in achieving scientific concepts is significantly effective (Al-Badri, 2016).

PhET Interactive Simulations project was founded in 2002 by Carl Wieman. It is one of the most distinguished virtual labs that have been produced as it includes research-based, free, and interactive science and mathematics simulations. Its contents have been accredited by many countries (PhET, 2020).

In general, virtual labs involve several features that enhance the learning experience, such as providing external tools connected to computer monitor to receive input data based on the work done by the learner. These tools may be available in laboratories for science experiments, for example, and can be dispensable according to the type of experiment to be simulated. Personal computers must also be available and connected to the Internet or a local network. This allows the learner to conduct experiments and learn at distance anytime and anywhere. The special software of these laboratories should be to be available in both their illustrative and survey types. Also, there must be guidance and control system for the work in virtual experiments, and this comes through direct guidance from the teacher or through the program itself which gives the teacher the ability to follow up the students' progress. Also, another capability that is available in virtual labs is the automatic recording of experiments performed by the students for future use (Sarhan, 2016).

Several studies Alkhaldi, Pranata, & Athauda (2016), Sarhan (2016), Al-Bawi, Abd and Ghazi (2016), Lynch & Ghergulescu (2017, March), and Gambari, Kawu, & Falode (2018) indicate that the employment of virtual laboratories has important educational benefits. They are a very suitable alternative to traditional labs because of their capabilities to individualize learning. They also give students immediate and semi-real-life experiences, and thus protect learners from any potential risks associated with conventional laboratories. In addition, they save much time, effort, and money. The learner can conduct the experiment for an unlimited number of times at his/her own convenience (i.e. at any appropriate time and/or place). These virtual labs stimulate the learner's imagination and visualization of some abstract concepts, theories, and laws, especially in Mathematics and Physics. They also allow the learner to experiment with clear steps with direct and immediate feedback. In addition to these advantages, these studies have agreed that virtual labs contribute to raising students' achievement level.

These laboratories develop students' self-learning and increase the accurate implementation of scientific theories and concepts, which in turn ease and facilitate better understanding of content and contributes to raising the achievement levels of learners. And this happens when incorporating a sound pedagogy, good support, detailed content, and tutor interaction (Alkhaldi et al., 2016).

In this regard, the researcher can conclude that most studies he reviewed agreed on the effectiveness of employing virtual labs in raising the achievement level among learners. The majority did not mention their disadvantages which the researcher can notice especially when interfering with teaching and learning: most notably the need for a specialized staff to work in these labs technicians, programmers, material experts and educational designers, and at the same time limited interaction compared to the real situation. One of the disadvantages of virtual labs is that they achieve few emotional – when compared with cognitive – goals, and reduce teamwork, communication, and networking skills (Baghdadi, 2014).

Besides, the researcher believes that although there are some drawbacks of these virtual laboratories that might exist, overcoming them is not so difficult since they are not major obstacles. At the same time, free laboratories and websites that provide these labs and educational content can be used for free. In a nutshell, they help to simplify and clarify some classroom situations in most school subjects. Just as virtual labs are one of the forms or strategies of implementing active learning, they are gaining ground as new and important teaching strategy and form of e-learning.

Even teachers perceive virtual labs as a technology that helped them overcome many of the classroom challenges like facilitating learning to slow learners and giving individual instant feedback as well as getting them engaged in learning and staying motivated (Lynch & Ghergulescu, 2017, July).

## 3. Methodology

### 3.1 Research design and participants

The researcher adopted a mixed methods approach design in conducting the current study. A quasi-experimental design was used while administering both the pre-and post-test to two groups: experimental and control. The experimental group was selected to learn the “fractions” unit through Virtual Laboratory, while the control group was taught the same unit, but through the traditional commonly used method. Then, students in the experimental group were interviewed to gain more understanding about their experience with the virtual lab (Creswell, Plano Clark, et al.,2003).

One of the elementary education schools (5-9 grades) was targeted in the Governorate of Muscat. Thirty (30) students were selected and equally divided into two groups: an experimental group (15 students), and a control group (15 students).

The variables of the current study were adjusted by selecting two groups of students with the same cognitive background. The researcher applied the study in one of the elementary schools in Muscat, which he was able to obtain an approval from the authorities to access and implement the study. He chose the fifth grade to control the school stage, and the same unit in mathematics was used in the interventional program to stabilize the content. Also, the researcher excluded 4 students for their absence from both pre-and post-tests. These procedures were followed to ensure validity and reliability of research results.

### 3.2 Instruments

- *Achievement test*

The Achievement test was developed by the researcher to be administered twice, as a pre-posttest to the experimental and control groups both before and after the intervention (using the virtual lab PhET with the experimental group). The researcher included clear instructions for the test and informed both groups that the test is not for real grades that would affect their real assessment at school. The test consisted of 20 items of two types, 10 multiple choice items and 10 completion items. One score was assigned for each correct answer, and a zero score for each wrong answer.

- *Interviews*

Semi-structured interviews were conducted with the participants in the experimental group (n=15) after the end of the treatment to reflect on their learning experience using the simulations website. The interview questions were developed by the researcher and were divided into two sections: ease of use and favoring the teaching method used.

- *Activities and components of virtual laboratory PhET guided by the students' textbook and the work of Hensberry, Moore & Perkins (2015)*

- Fraction representation: Used to present the educational content to students, where student can choose the type of template that represents the fraction shape with the teacher's guidance.
- Fraction laboratory: A free space through which students can write the fractions or fractional numbers required. The teacher can ask some students to create the fraction or fractional number and ask other students to put the appropriate shape, and then perform a group discussion about these concepts.
- Building fractions: Activities and exercises, consisting of a set of ten levels. The learners can choose the level they want and move gradually from one level to another. This is where the students are assessed on how to build and write a fraction. The students can build the fractions

using either a given form, or they can draw the shape that fits the given fraction.
- Matching game: According to this game, the students match the fraction with the shape it represents, or match two forms representing the same fraction. The students select one of the shapes or fractions from the bottom squares, put it in the pan at the top, and raise the other form in the second pan, then press the word check. If the answer is correct, what was chosen above will be transmitted, with immediate feedback and reinforcement, or return to their place to try again, and thus to the end of shapes and fractions.

### 3.3 Designing the instructional settings

The researcher used the Dynamic Instructional Design (DID) model that was developed by Lever-Duffy & McDonald (2011) to set the educational design. This model is very suitable for employing technology in the educational process. The design consisted of six stages as follows: Knowing the learners and their characteristics, articulate the behavioral objectives that describe students' performance, establishing the learning environment including all the educational and physical aspects that support the learning situation, identifying the suitable teaching and learning strategies that need to be implemented to achieve the behavioral objectives, identify media, materials and technology that support each strategy, and lastly evaluate students' learning and the instructional design process itself.

The flexible blended model (Staker & Horn, 2012; Powell et al., 2015) was used to introduce the content to the experimental group. Content was presented through the PhET Laboratory and teachers supported and enriched students' learning through discussion and teacher's guidance.

### 3.3 Administering the research instruments

To achieve the objectives of the study, the researcher divided students into two groups: control and experimental, each of which consists of 15 students chosen randomly. Then he conducted, with the help of a trained teacher, the pre-test of academic achievement to measure the achievement level of students in both control and experimental groups, and to ensure the equivalence of these groups, through their convergent results on the post-test. After that, a trained teacher started teaching "fraction" unit using the virtual laboratory to experimental group students, while teaching the same unit to the control group using the traditional method. Subsequently, he administered the academic achievement post-test to both experimental and control group students to measure the level of achievement following instruction. Also, he conducted interviews with the students in the experimental group after ending the experiment. Finally, results were obtained and statistically analyzed.

## 4. Results

### 4.1 First research question

After conducting the instructional intervention, results of the pre-test and post-test for both the experimental and control groups were collected and processed using the statistical analysis software SPSS to answer the study's first question which is: "What is the impact of employing a blended learning environment enhanced with web-based virtual laboratory on raising fifth-grade students' achievement in mathematics?".

Accordingly, Wilcoxon Signed Ranks Test was applied to examine the differences between pre and post-tests of the study groups. Also, to compare between the post administration of the achievement test in the two groups, the Mann-Whitney Ranks Test was applied.

| Achievement Test | N | Mean Rank | Sum of Ranks | Z | Sig |
|---|---|---|---|---|---|
| Negative Ranks | 0 | 0 | 0 | -3.464 | 0.001 |
| Positive Ranks | 15 | 8.00 | 120.00 | | |

**Table 1** - Comparison between pre and post-test in mean ranks for Achievement in the control group, using the Wilcoxon Ranks Test.

As Z value is (-3.464) with significance level at (0.001) as shown in Table 1, the presence of significant differences between the mean ranks in achievement test for the sake of the post-test can be realized in the control group. This means that the students have shown improvement in learning the mathematical abstract concepts.

| Achievement Test | N | Mean Rank | Sum of Ranks | Z | Sig |
|---|---|---|---|---|---|
| Negative Ranks | 0 | 0 | 0 | -3.493 | 0.000 |
| Positive Ranks | 15 | 8.00 | 120.00 | | |

**Table 2** - The difference between pre and post-test in mean ranks for Achievement in the experimental group, using the Wilcoxon Ranks Test.

As Shown in Table 2, Z value is (-3.493) with significance level (0.000). This means that there are significant differences between the mean ranks in achievement test for the sake of the post-test in the experimental group. This implies that the there is an improvement in the students' performance in the mathematical abstract concepts test.

It can be noted from Table 2 that there is a clear difference between the pre-test and the post-test of the experimental group in favour of the post-test, as Z value is (-3.493) with significance level $0.000<0.05$. At that point, the researcher noticed a change in the students' acceptance of learning mathematics through using the web-based virtual laboratory, unlike the traditional normal method in which the learners did not give any abnormal interest (Aşıksoy & Islek, 2017).

| G | N | Mean Rank | Sum of Ranks | U | W | Z | Sig |
|---|---|---|---|---|---|---|---|
| CG | 15 | 8.77 | 131.50 | 11.500 | 131.500 | -4.320 | 0.000 |
| EG | 15 | 22.23 | 333.50 | | | | |

**Table 3** - The result of Mann-Whitney Ranks Test measuring the mean ranks in Achievement between the post-tests of the two groups.

Results in Table 3 shows significant differences in Achievement test between the post-tests of both groups for the sake of the experimental group, where U = 11.500, Z= -4.320, p>.05, r=0.000.

### 4.2 Second research question

To answer the study's second question which is: "What are the students' perceptions regarding the method used in learning abstract mathematical concepts?", all students in the experimental group (n=15) were interviewed to know their opinion on learning abstract mathematical concepts using the web-based virtual laboratory. After doing the transcript and coding process, results showed four main themes as shown in Figure 1.


**Figure 1** - Interview Themes.

In general, the students were found to highly favor using the simulation website within the blended learning settings. They commented on the clarity of the virtual lab, for example one participant said: "*it was easy for me to use without help*". Also, they expressed their happiness about the graphical interface describing it to be "*cheering & fun*". Moreover, they expressed their satisfaction about the teaching method used and how the teacher's guidance and group discussion supported them while working on the simulation activities. One of the participants said: "*The best thing I liked about these lessons is the group work and teacher's guidance to us*". Finally, the immediate feedback that students receive from the software during their learning was favored by many students.

Overall, the results of the interview can explain the significant points of strengths in the experiment and can interpret the significant results of the achievement test applied to the experimental group.

## 5. Discussion

The current study sought to answer the following question: "What is the impact of employing a blended learning environment enhanced with web-based virtual laboratory on raising fifth-grade students' achievement in mathematics?" and then, it sought to answer: "What is the students' opinion on learning abstract mathematical concepts using the web-based virtual laboratory?"

Referring to the above results, the research indicates that the change in the students' acceptance of learning mathematics that employs the use of virtual laboratories will transform the students' learning from the abstract state to the concrete state, that is close to reality, and here the students can significantly engage in learning experience as reported by Xu and Ke (2016).

Moreover, the pedagogy used with the experimental group can be a main explanation of increasing the students' understanding and performance. It depended on implementing the Flex blended model, where the abstract concepts of Mathematics were taught mainly using the virtual lab, then discussions and offline activities were used within the traditional classroom environment. The teacher's role was to provide help and support, and initiate discussions to enrich and deepen learning. This allows students to progress according to their individual needs (Horn, Staker & Christensen, 2014; Ardiyati, Wilujeng, & Kuswanto, 2019; Dasilva, Kuswanto, & Wilujeng, 2019).

Based on the difference in means between the two groups which was in favor of the experimental group and based on the previously reported results, the researcher can confidently report that the independent variable (i.e. using virtual laboratory within a blended learning environment) has an evident effect on the dependent variable (i.e. academic achievement).The researcher attributed this to the advantages and capabilities of virtual labs in raising learning motivation and attracting the attention of learners towards achieving all the required instructional objectives. This is confirmed by some previous studies like Sarhan (2016), Lynch & Ghergulescu, (2017, March), and Al-Hazimi (2017).

It seems that the features of the employed simulations website assisted students with improving their learning experience through allowing them to get involved in many activities and take decisions about their learning. Allowing students to choose the type of templates that represent the fraction shape and providing them with a free space where they can build new fractions for their peers, will have helped them to go beyond acquiring basic low-level knowledge and gain confidence to achieve higher-order thinking skills (Gunter & Gunter, 2015).

Students were exposed to many activities and exercises supported with immediate reinforcement and direct constructive feedback to their performance, which positively affected their learning (Siochrú, 2018). Students also were challenged to move through ten different difficulty levels during their learning, and they started to gain confidence as they met the challenge. They felt that they were capable of achievement if they put in a good faith effort (Dicheva, Dichev, Agre, & Angelova, 2015; Li & Keller, 2018).

Apart from the virtual lab specific features, the design of learning proved effective in achieving the required aims. The study employed the Dynamic Instructional Design (DID) model that was developed by Lever-Duffy & McDonald (2011) for guiding the instructional design of the experiment. The power of that model lies in its capability to ensure creating an effective learning environment based on designing technology infused instruction. The researcher emphasizes the importance of choosing the suitable technology and teaching method in accordance with the characteristics of learners in order to help them achieve their instructional goals (Sun, Lin, & Yu, 2008; Brown & Green, 2015). The design consisted of six stages starting with analyzing learners' characteristics in order to know more about them, and hence build the right plan, passing on to identifying the suitable objectives and establishing the learning environment to act as a successful communication tool, and ending with evaluating learning using both formative and summative assessment procedures, and finally verifying the validity and quality of the whole design through validating all its stages by specialists.

Although the researcher employed the behavioral theory through activities and exercises, the social constructivism theory was the basis of the experiment, where students urged to explore and discover knowledge through the development and investigation of what needs to be solved in different activities and then be involved in group discussion with their peers to develop learned concepts.

One of the strengths of this study was represented in deployment of a flexible blended learning model (Staker & Horn, 2012; Powell et al., 2015; Bunnell, 2017) where most of the content was delivered online, but within a traditional school setting. The teacher was able to give support to students when needed and create group discussions. This practice provided great opportunities for students to learn at their own pace while benefiting from the teacher's continuous support and peer interaction. They managed to reach new levels that were difficult for them to reach without support (Smagorinsky, 2018; Ardiyati et al., 2019; Dasilva et al., 2019). This is also reported by Hensberry, Moore & Perkins (2015) who found that combining discourse-rich environment with simulation in one learning situation, leads to motivate students and support their understanding to fraction ideas.

Generally, one can say that the careful planning led the virtual laboratory to help students achieve the instructional objectives in an optimum learning environment that managed to overcome many communication barriers.

Finally, the researcher found out that the results of the current study were consistent with many previous studies including Moyer-Packenham and Suh (2012), Kablan (2016), Sarhan (2016), Al-Bawi et al. (2016), Gambari et al. (2018), and Reiten (2018), where a positive effect was reported when employing virtual laboratories in teaching mathematics compared to teaching in a traditional manner.

The results of the current study can be significantly beneficial for introducing a rigorous vision to facilitate teaching abstract mathematical concepts using simulations websites and instilling the conviction of specialists in designing curricula of the usefulness of employing different techniques in teaching such concepts in Mathematics courses in the different academic stages, and its role in increasing the learning outcomes level. Also, it contributes to divulge the usage of blended learning pedagogical model in integrating technology within the school settings in an effective way that supports students' learning.

## 5. Conclusion

Through the presentation of the results and their statistical interpretation, the researcher concludes that there is a clearly positive effect in the use of PhET simulations virtual laboratory within blended learning settings on the achievement of the fifth-grade students in mathematics in the fractions unit. This might be due to the pedagogical model used in teaching which allowed the students to work online as well as involve in group working and discussions with their peers and teacher. Also, the importance of teaching mathematical concepts with tools that raise the attention of students, and the need to move away from excessive abstraction, which affects the imagination of the students and their good understanding of math problems, and hence stimulate and attract students towards interactive electronic content.

This conclusion agreed with the studies mentioned in the theoretical framework, and through what was put forward in there. Based on the findings, the researcher recommends using virtual laboratories to reform curricula and simplify the abstract concepts of mathematics at various stages, especially in the second stage of basic education and public education. Also, it is recommended to incorporate virtual laboratories in the plans for the professional development of teachers and how to employ them in teaching instructional concepts. Finally, it is recommended to conduct similar research studies to identify the impact of simulation virtual laboratories websites on raising attitudes, motivation, and develop problem-solving skills among students in learning mathematics.

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