

The Impact of Inquiry-based Virtual Labs on 11th Grade Lebanese Students' Achievement in a Biotechnology Unit

Amina Harbali

Lebanese University, Doctoral School of Literature, Human and Social Sciences, Faculty of Education, Sin-el-fil, Lebanon

Abstract: *This study aims to investigate the effect of using inquiry-based virtual labs (V-Labs) on 11th grade Lebanese students' achievement in genetic engineering. The differential impact of gender is also explored. This study uses a quasi-experimental, control-group design whereby students in the experimental group received inquiry-based V-Lab lessons designed by the researcher and students in the control group received lessons based on the 5E inquiry model. Participants included 200 students from two private schools and two public schools in Beirut. A pre/post-test was used to measure student achievement. Results showed that students who were taught using V-Labs showed better achievement in genetic engineering than those who only received the inquiry-based approach. In addition, female students showed better achievement when they received the V-Lab approach while males showed better achievement with the 5E approach.*

Keywords: Science education, genetic engineering, 5E inquiry model, virtual labs, gender

1. Introduction

Within the field of K-12 education, there has been a call for using student-centered approaches across different subject areas, including science. The aim of this movement is to develop 21st century citizens that are capable of engaging in critical thinking and, thus, becoming influential members of society (Barron & Darling-Hammond, 2008). This requires that education shift from traditional teaching methods to methods that require students to engage in authentic, real-world learning tasks (Buchanan, Harlan, Bruce & Edwards, 2016). One way to achieve this is through inquiry-based learning (IBL; Buchanan et al., 2016). IBL approaches have been associated with higher levels of academic achievement and conceptual understanding (Minner, Levy & Century, 2009), content retention (Donald, Bohm & Moore, 2009), critical thinking skills (Fu & Liu, 2016) and scientific literacy (Basaga, Geban & Tekkaya, 1994). When compared to traditional teaching methods, they have been shown to be more effective (Aktamis, Hiğde & Özden, 2016).

Using technology in combination with IBL has the potential to enhance engagement in the learning process and significantly improve student growth and learning (Cool, 2015). Among the technological tools that can be integrated with IBL is the virtual laboratory (V-Lab), a computer-based online platform that involves virtual simulations of science processes or explanations of topics (Maldarelli et al., 2009). V-Labs are believed to support IBL in learning science as they offer better opportunities for understanding and clarification of abstract and complex scientific processes and concepts (Doukeli, 2012). One abstract concept in science that students find particularly difficult to learn is that of biotechnology, including genetic engineering (Chen & Raffan, 1999; Özel, Erdoğan, Uşak & Prokop, 2009). Biotechnology is defined as the use of biological processes, organisms or systems to create

products that improve the standard of human life (Goldberg & Williams, 1991).

The new Lebanese curricula developed in 1997 included the domain of biotechnology as part of the secondary curriculum. Inquiry-based approaches can be effective in teaching this content because it allows students opportunities to engage in critical thinking skills as well as follow the same scientific processes that are used in the field. Learning materials used in scientific inquiry must be interesting and appealing to students (Gillies & Nichols, 2014). Nowadays, students are becoming more and more technologically savvy. Therefore, using technology in the classroom may be a way to get them more engaged, especially with a topic with which they are not very familiar (Rosenbaum, Klopfer & Perry, 2007). In addition, teaching biotechnology involves experimental methods that are not capable of being implemented in a traditional laboratory due to practical and ethical reasons. The use of V-Labs can be helpful in addressing these limitations; however, it is evident that science classrooms in Lebanon lack the use of technology in ways that promote scientific processes and skills (Chaaban & Moloney, 2016). In fact, most Lebanese schools seem to apply a traditional method of teaching where the students are not involved in the learning process and they are only receivers of information (Abdel-Khalik et al., 2004). Thus, the current study aims to study the effect of using V-Labs within an IBL framework on 11th grade Lebanese students' achievement in genetic engineering. Since findings of gender differences on the impact of V-Labs has been inconsistent (e.g., Blonder et al., 2015; Ješková et al., 2016), this study also aims to check for the difference between the academic achievement of males and females.

2. Literature Review

2.1 Inquiry-based Learning (IBL)

IBL is a student-centered approach that focuses on generating information and creating meaning through a personalized approach (Dagys, 2017). The constructivist theory of learning has four main principles on which IBL is based: 1) Learning is built upon previous knowledge; 2) Learners make their own meaning; 3) Social interactions are needed to facilitate the learning process; and 4) Authentic learning tasks are needed for meaningful learning (Krahenbuhl, 2016). The ultimate goal of IBL is to ensure that students move towards the path of intellectual curiosity and understanding (Healey, 2005). IBL approaches vary, but the most common one is Bybee's 5E Instructional Model which involves five cognitive stages: 1) Engage, 2) Explore, 3) Explain, 4) Elaborate, and 5) Evaluate (Bybee & Landes, 1990). The 5E model involves learners in generating investigable questions, planning and conducting investigations, gathering and analyzing data, explaining their findings, and sharing and justifying their findings with others (Ramsey, 1993). The model can be used as a framework for a sequence of daily lessons, individual units, or yearly plans (Bybee, 1997).

As opposed to traditional approaches, IBL aims to develop students' information processing and problem-solving skills rather than emphasize knowledge of facts and procedures that are taught as monotonous drills holding little value or meaning (Hughes, 2005). Therefore, students find themselves more engaged in the creation of knowledge (Healey, 2005) which makes them more eager to learn about a subject and facilitates their construction of in-depth knowledge regarding it. Minner et al.'s (2009) review of 138 studies published between 1984 and 2002 showed that IBL had significantly positive effects on K-12 students' science achievement and conceptual understanding. Similarly, Aktamis et al. (2016) conducted a meta-analysis on studies published between 2005 and 2015 and found that students receiving IBL had significantly higher academic achievement, better science process skills and more positive science opinions than those receiving traditional teaching methods.

2.2 IBL-based Virtual Labs

Technology used simultaneously with IBL can prove to be a strengthening tool in acquiring knowledge about scientific concepts and nurturing skills of measurement, analysis, and information processing (Crawford et al., 2014). These technologies can help transform science "from canned labs and the passive memorization of content to a dynamic, hands-on, authentic process of investigation and discovery" (Barstow, 2001, p. 41). Technology-based IBL also allows students to be more engaged in realistic scientific inquiry experiences, especially when dealing with abstract concepts (Litchfield & Mattson, 1989). Furthermore, students are given opportunities to predict, observe and explore the effects of dependent variables in more complex experiments (Edelson, 2001). This ultimately results in a cognitive shift in students'

scientific thinking which emphasizes "thinking, conjecture and talk about the scientific method, about the reasons, limitations and benefits of carrying out controlled experimentation, and about qualitative interpretation of evidence" (Miller, 2001, p. 194).

The use of computer-based instructional materials such as V-Labs, especially for laboratory science instruction, has a number of benefits including, but not limited to, safety, cost-efficiency, minimization of error, flexibility, efficiency, and spatial dimensions (Heradio et al., 2016). V-Labs are useful for presenting science as a process and emphasizing science concepts (Liu et al., 2001). They let students observe the scientific process in more detail compared to traditional teaching methods or partially completed experiments of the real laboratory environment (Marx et al., 2004). The interactive nature of the equipment can present illustrative representations of physical phenomena to allow students to construct links between scientific theory and empirical evidence (Hennessy et al., 2007). V-Labs also deepen knowledge and understanding by allowing learners to freely make errors and correct them themselves through repeated practice (Ardac & Akaygun, 2004; Jeschke, Richter, & Zorn, 2010). Students in V-Labs get the feeling of real lab environments in which they can transform their abstract knowledge into real-world knowledge by conducting experiments (Woodfield, 2005). Furthermore, interacting with V-Labs enhances students' skills in conducting experiments, manipulating materials and equipment, collecting data, completing the experimental process in an interactive way (with boundless supplies), and preparing reports (Subramanian & Marsic, 2001).

2.3 Gender Differences

There is little research examining gender differences in IBL. The research that does exist shows somewhat conflicting results. Ješková et al. (2016) conducted a study to determine the impact of an inquiry-based program on students' inquiry skills in physics, informatics, and math. Results of their study showed that both males and females showed equal gains in inquiry skills. Similarly, Jocz, Zhai and Tan's (2014) study indicated that both males and females showed a higher interest in science after receiving inquiry-based instruction. Furthermore, Cigdemoglu and Geban (2015) found that both males and females had the same gains in conceptual understanding when given instruction based on the 5E learning cycle. On the other hand, another study done by Blonder et al. (2015) showed that females had better post-test scores than males after going through a few weeks of an inquiry-based lab.

There is also only a couple of studies examining the impact of V-Labs, specifically, on males and females. Gambari et al. (2017) examined the impact of using V-Labs on gender and achievement levels of chemistry students in secondary schools in Nigeria. Results showed that both male and female students showed improvements; however, males had better gain scores. In contrast, a study done by Bergey, Ketelhut, Liang,

Natarajan and Karakus (2015) showed that although males had higher self-efficacy in the skills needed to engage in a virtual environment, both males and females showed similar levels of scientific inquiry and achievement.

2.4. Biotechnology in Science Teaching

The domain of biotechnology significantly advanced in the 21st century. There are multiple ways in which biotechnological methods can be used including, but not limited to, tissue culture, cloning, and genetic engineering (Chabalengula, Mumba & Chitiyo, 2011). Biotechnology has the ability to transform various fields as it has many applications in industries such as medicine, health, environment and agriculture (Chabalengula et al., 2011). Progress in the field is simultaneously restricted by the ethical and social implications associated with it. This has necessitated that students be equipped with the necessary scientific literacy skills and knowledge of biotechnological methods in order to be responsible problem-solvers and decision-makers with regards to controversial issues in this field (Chabalengula et al., 2011). In fact, schools play a major role in shaping the mindsets of students and giving them insights into the advancements occurring within the domain of biotechnology (Steele & Aubussan, 2004).

Despite the importance of this scientific field, there is very little research done on secondary students' understanding of biotechnology concepts. Most have been done on undergraduate students. The research that does exist indicates that students have limited understanding of this domain. For example, Dawson and Venville (2009) conducted semi-structured interviews on middle school and high school students and found that students' reasoning and argumentation skills in biotechnology indicated inadequate scientific literacy. Dawson and Schibeci's (2003) study revealed that when high school students were asked to list examples of biotechnology, about 33% of them were unable to answer. Also, students who did provide examples tended to mention the most commonly thought of areas in biotechnology including cloning, genetic engineering and genetically modified foods.

Biotechnology V-Labs use technologies like animations, simulations and remote-triggered experiments which have been shown to have an increasingly important role in teaching scenarios (Chu, 1999; Yarden & Yarden, 2011). This is ideal for teaching a controversial topic like biotechnology where real-life application within a classroom context is not feasible and, in many cases, unethical. The topic of biotechnology is also ideal for IBL since the methods and techniques that scientists use in biotechnology align with the basic principles of IBL. However, no studies have been done to investigate the impact of V-Labs, in general, or inquiry-based V-Labs, in specific, on secondary students. Very few studies have been conducted on university students majoring in biotechnology (e.g., Dalgarno, Bishop, Adlong, & Bedgood, 2009; Dobson, 2009). Since science at the secondary level becomes increasingly complex and abstract, it is important to study instructional approaches that would simplify its teaching.

2.5 The Lebanese Context

In Lebanon, ministry has full control of the public education sector and considerable control over the private sector due to the high stakes examinations and licensures. Though some private schools use a foreign curriculum, a significant portion of the schools adopt the Lebanese curriculum which provides common content for all students until 11th grade whereby students may choose to follow the humanities track or the science track. All students take science in some form, but with a varying number of periods per week. The study of biotechnology has been part of the Lebanese life science curriculum since 1997. The notion of genetic engineering is briefly explained in grade 10 and extensively in grade 11 since, during this year, they cover a whole chapter about genetic information. This prerequisite information makes the biotechnology theme easier to students once they reach the 12th grade. The language of instruction of science at the secondary level is either English or French.

The Lebanese science curriculum does not integrate the use of inquiry skills in a coherent and well-sequenced manner (BouJaoude, 2002). In addition, the curriculum's definition of inquiry is limited to the steps of the scientific method and the activities included encouraged "hands-on" but not "minds-on" science (Abdel-Khalik et al., 2004). Also, although there is evidence that Lebanese teachers are still using traditional methods of instruction (Abdel-Khalik et al., 2004). Moreover, Lebanese teachers infrequently integrate technology in their teaching, and when they do, they use primitive methods such as PowerPoint (Chaaban & Moloney, 2016).

In terms of the field of biotechnology, only two studies were found that dealt with the topic. Haidar et al. (2014) found that secondary students in the Beirut and Mount Lebanon region had relatively low knowledge of biotechnology topics especially with regard to recombinant DNA, cloning, DNA transfer, and genetically modified foods and animals. Haidar and Abou Tayeh (2015) aimed to analyze the effects of teaching a biotechnology module using a socio-constructivist framework on the opinions and arguments of 11th grade students. The framework consisted of using constructivist approaches along with social interactions, which are similar to inquiry-based approaches. Results showed that students' argumentation skills progressed from simple with one justification on the pre-test to more complex with multiple justifications on the post-test. They were able to use their scientific knowledge to make decisions and arguments relating to social, ethical, medical, scientific and religious aspects.

2.6 The Current Study

This study aims to add to the literature on using V-Labs in the domain of biotechnology by addressing several gaps. First, most previous studies in this area have been conducted on college students. Second, studies on gender differences have found to be inconsistent. Third, no work has been done in Lebanon till now to evaluate the impact of V-Lab on students' achievement in biotechnology, specifically genetic

engineering. Therefore, for the purpose of this study, the following research question is addressed: What is the impact of inquiry-based V-Labs on 11th grade Lebanese students' achievement in genetic engineering? Is there a differential impact by gender?

3. Methodology

This study follows a quasi-experimental research design with a pre-test/post-test control-group design. The experimental group received instruction on a genetic engineering unit using an inquiry-based V-Lab approach while the control group received the traditional 5E inquiry approach.

3.1 Participants

The sample of students for this study was taken from public and private schools in Beirut that used English as the language of instruction for biology and were equipped with computers. Schools were also chosen to have two 11th grade scientific sections, a number of students ranging from 20 to 24, and classrooms that included males and females. The final sample consisted of 200 11th grade students with 100 (50%) of them being from public schools and 100 (50%) of them being from private schools. There was a total of 98 students (49%) in the experimental group and 102 (51%) in the control groups. Of the total sample of students, 94 (47%) were female and 106 (53%) were male.

3.2 Instrument: Pre-test/Post-test

A set of pre-test and post-test items were constructed by the researcher in cooperation with the participating students' teachers. The questions were used to evaluate students' understanding of certain phenomena related to genetic engineering and, thus, determine the outcomes of the intervention and its effectiveness. Separate test items were used for each of the pre-test and post-test in order to avoid a carryover effect. However, both tests had a parallel structure and same level of difficulty and measured the same sets of skills. The format of the items was similar to the format that students typically encounter in their regular biology lessons. Questions consisted of two types: 60% subjective (synthesis, analysis and interpretation of documents, as well drawing a graph or a table) and 40% objective (multiple choice and true/false questions). The questions were written based on the objectives set by the Lebanese curriculum and according to the recommended skills that students needed to acquire. Students were given 45 minutes to complete each test. The minimum score a student could receive on the pre/post-test was a 0 and the maximum score was a 20. The higher the score, the better the achievement level.

3.3 Data Collection Procedures

Each of the two 11th grade classrooms in each participating school was randomly assigned to be a control or experimental group. All students were given the pre-test. Then, both the control and experimental groups received a total of four

sessions on the genetic engineering topic. The first and last sessions were the same for both groups. In the first session, students were introduced to all the terms related to the unit (e.g., genes, genetic engineering, DNA, and foreign antigens). The fourth and last session was a "summing up" session where students discussed what they learned with their teachers. For the control group, the second and third sessions consisted of two hands-on activities following the 5E inquiry model. The teachers in this group referred to the Lebanese textbook as well as their own knowledge to explain all the necessary details related to genetic engineering. As for the experimental group, the second and third sessions consisted of two separate V-lab activities that were developed by the researcher for the purpose of this study. These lessons not only used V-Labs to teach different concepts in genetic engineering, but they also followed inquiry-based approaches to deliver the lessons. It is worth noting that the researcher provided training to the teachers who had not used a V-Lab previously. At the end of the four teaching sessions, both groups were given the post-test.

3.4 Data Analysis Procedures

The Statistical Package for the Social Sciences (SPSS) Version 22 was used to conduct the analyses. Paired samples *t*-test were used to compare the pre-test and post-test scores in each of the experimental and control groups to determine any gains in knowledge. In addition, a 2x2 ANCOVA (two-way ANCOVA) was done to determine the main effects and interactions effects of gender and group. There were two independent variables each with two levels: gender (males and females) and group (experimental and control). The dependent variable was the post-test and the covariate was the pre-test. A significance level of $\alpha = .05$ was used.

4. Results

For the control group, the post-test mean score ($M = 10.30$; $SD = 1.77$) was higher than the pre-test mean score ($M = 8.85$; $SD = 1.68$). For the experimental group, the post-test mean score ($M = 11.17$; $SD = 2.29$) was higher than the pre-test mean score ($M = 9.36$; $SD = 1.98$). A paired samples *t*-test was done to determine whether or not these score increases were statistically significant. In both the experimental and control groups, students scored significantly higher after receiving instruction (experimental $t(101) = -9.377$, $p = .000$; control $t(97) = -10.006$, $p = .000$).

Results of the two-way ANCOVA indicate that, when controlling for prior scores on the genetic engineering test, the main effects of group was significant [$F(1, 195) = 6.443$, $p = .012$] while that of gender was not [$F(1, 195) = .680$, $p = .411$]. This means that students in the experimental group ($M = 11.03$) had significantly better achievement than students in the control group ($M = 10.45$). As for the interaction effect between group and gender, it was found to be significant [$F(1, 195) = 7.191$, $p = .008$]. This means that the difference between males and females is dependent upon whether they

are in the experimental or control group. Specifically, in the control group, males ($M = 10.65$) had significantly higher scores than females ($M = 10.25$). On the other hand, in the experimental group, females ($M = 11.44$) had significantly higher scores than males ($M = 10.63$). In other words, females benefitted more from the inquiry-based V-Lab approach while males benefitted more from the 5E approach.

5. Discussion

The purpose of this study was to explore the impact of inquiry-based V-Labs on 11th grade Lebanese students' achievement in genetic engineering and to determine whether there was a difference between males and females. Results showed that the inquiry-based approach alone as well as combining V-Labs with an inquiry-based approach were both effective in significantly increasing student achievement. The positive impact of inquiry-based approaches in increasing student achievement has been consistently supported in previous research (Aktamis et al., 2016; Minner et al., 2009) especially when applied on abstract scientific concepts (Cigdemoglu & Geban, 2015). Similarly, previous studies confirm that using technology, such as V-Labs, in combination with IBL, has positive impacts on student learning, including academic achievement (Dalgarno et al., 2009; Dobson, 2009; Leonard, 1992; Maldarelli et al., 2009).

Findings also indicated that students who received the V-Lab inquiry-based approach had significantly better achievement than students who received the inquiry-based approach alone, when controlling for pre-test scores. This suggests that adding a V-Lab component to teaching inquiry-based genetic engineering has an advantage over using inquiry-based approaches alone. To the knowledge of the researcher, there are no studies that have been done to compare regular IBL approaches with inquiry-based V-Lab approaches. Therefore, a comparison between the findings of this study and previous studies is not possible. However, previous research does suggest that the use of V-Labs is associated with significant increases in academic achievement (Marx et al., 2004). This is a result of better conceptual understanding in which learners using V-Labs are given opportunities to engage in individualized learning, enhance their critical thinking skills and be involved in repeated practice (Ardac & Akaygun, 2004; Hatherly, et al., 2009; Jeschke et al. 2010; Koretsky et al. 2008).

The application of V-Labs in fields such as biotechnology, including genetic engineering, is especially important for enhancing achievement and understanding (Zhang et al., 2004). Previous studies in Western countries (Chen & Raffan, 1999; Özel et al., 2009) and one study in Lebanon (Haidar et al., 2014) indicated that students lack adequate knowledge of different areas of biotechnology, including genetic engineering. By incorporating inquiry-based V-Lab approaches in this domain, students can see representations of physical phenomena and, thus, make relationships between scientific theory and empirical evidence (Hennessy et al., 2007). It also allows students to engage in metacognition by

providing them with tangible means of monitoring and regulating their own learning (Schraw et al., 2006). This, in turn, leads to better academic achievement.

Regarding gender differences in achievement, findings indicate that females receiving inquiry-based V-Labs performed better than those who received inquiry alone. On the other hand, males receiving inquiry alone performed better than those who received inquiry-based V-Labs. This finding conflicts with previous research which suggests that males tend to prefer the incorporation of technology in their learning (Kay, 2006). Previous research comparing the academic achievement of males and females using V-Labs have indicated inconsistent results. Some have revealed that both males and females have similar achievement (Bergey, et al., 2015) while some have revealed that males perform better (Gambari et al., 2017). However, it is worth mentioning that none of these studies have looked at gender differences using two different approaches (inquiry-based V-Labs and IBL alone).

6. Limitations

There were several methodological limitations to this study. First, the schools were chosen based on convenience and on a very specific set of criteria. Second, the sample only consisted of 11th grade students in the scientific section. Therefore, the results of this study may not apply to secondary students in other grade levels or other scientific tracks. Third, there was some period of time that the students in the control group did not have activities to complete while those in the experimental group did. This may have lead students in the control group to forget some of the acquired knowledge which, in turn, may have impacted how the control group students performed on the post-tests compared to the *experimental group*. A fourth limitation was that teachers were the ones implementing the interventions and administering the pre-test/post-test without the researcher's presence. Therefore, it is difficult to determine whether or not the teachers implemented the two teaching approaches as planned or how much help they provided to students during the pre-test and post-test.

7. Future Research

The outcomes of this study provide many potential avenues for future research. First, there should be further investigation on the factors that impact gender differences in the use of V-Labs. In particular, qualitative research can explore the reasons why Lebanese female students responded better to the V-lab approach than males did. This is especially true since the literature already shows conflicting results in terms of gender differences. Therefore, more research is needed to reach a consensus in this area. Second, since no studies have been done on the use of V-Labs in Lebanon in any field, further studies could also investigate the impact of using this approach for other subjects such as mathematics, physics, and chemistry. In addition, the implementation of V-Labs in other concepts and domains in biology can be further explored. By conducting these types of studies, it would help researchers to

identify whether such an approach yields positive results across various domains. Another potential area of future research is to conduct experimental studies that compare the effects of traditional teaching approaches (i.e., lecture based), inquiry-based learning and inquiry-based V-Labs. This study only explored the impact of the last two approaches, but it may also be useful to see how those approaches compare to traditional ones.

8. Implications for Practice

Introducing V-Labs in students' learning activities in Lebanon can have the potential to improve students' academic achievement as indicated by the findings of this study. This study also emphasized gender differences. Teachers should keep this in mind when preparing lesson plans in order to customize them to target the needs of both genders. Based on the results of this study, it may be necessary to find means to attract male students to get more involved and engaged in the use of V-Labs. Whenever they are preparing a lesson, teachers may consider students' interests and preferences. At the secondary level, this can be achieved by simply asking the students themselves for feedback and for suggestions for improvement. This will allow students to feel like they are even more involved in the learning process.

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Author Profile



Amina Harbali received a B.S. in Biology in 1987, a T.D. in Science Education in 1990, and an M.A. in Science Education in 2000 from the American University of Beirut. She is a PhD candidate in Science Education, Didactics of Biology from the Lebanese University. Since 1988, she has been coordinating and teaching Biology sessions at multiple private schools. Since 2009, she has conducted and participated in multiple workshops at the American University of Beirut. She was a member of the TAMAM team for education reform. She currently works as a principal in Beirut Modern School and as an instructor at the Arab Open University.