# Development of Scientific Literacy through Guided - Inquiry Learning Approach in Biology

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**Abstract:** ***Scientific literacy has been maintained as a major goal of science education. The Educational systems emphasize on science as a body of knowledge ignoring the other aspects of scientific literacy. The present study aims to investigate the effect of scientific guided inquiry on fostering students' all aspects of scientific literacy. A sample of 18 students from grade 10 in a private school in Beirut participated in this study, whereby Biology was taught to the class using the scientific guided inquiry method. Pre and post-tests VASS survey were administrated to the students to compare different aspects of scientific literacy before and after the intervention. Results of the study show that scientific guided inquiry foster significantly the development of all the aspects of scientific literacy.***

**Keywords:** Scientific Literacy; Inquiry-based learning; Guided Inquiry

## 1. Introduction

Scientific literacy has been maintained as a major goal of science education policy and practice and as the key learning outcomes in education for all students (Wenning, 2006). There is widespread agreement about the urge to foster scientific literacy to enable citizen making decisions about health and personal, social, and ecological wellbeing (OECD 2018).

Many efforts have been exerted by Science for All Americans with American Association for the Advancement of Science [AAAS] (1989) and Benchmarks for Science Literacy (AAAS, 1993) to improve scientific literacy. They established Project 2061 that was a long-term initiative product of one of the most important projects in USA. They considered scientific literacy as a main goal for science education and initiated reform in science education.

In addition, The National Science Education Standards (National Research Council [NRC], 1996) contributed to the reform in science education by setting the standards for achieving scientifically literate society.

## 2. Scientific Literacy

Nowadays, science educators believe that scientific literacy is a multidimensional concept including science concepts and ideas, the nature of science, and the interaction of science and society (Chatila, 2016 & Laugksch, 2000).
Chatila (2016) considered that an individual is scientifically literate when he/she is developing competences to get engaged in the world of science and technology.

Chiapetta, Sethna, and Fillman (1993) proposed four dimensions or themes for scientific literacy: science as a body of knowledge, science as a way of thinking, science as a way of investigation, and science and its interaction with technology and society. Based on these four dimensions, BouJauode (2002) developed a framework that includes four dimensions or aspects of science literacy; aspect 1: the knowledge of science, aspect 2: the investigative nature of science, aspect 3: science as a way of knowing, and aspect 4: the interaction of science, technology and society.

The Program for International Student Assessment PISA (2015) addressed scientific literacy to investigate how well 15 year-old students from over 80 countries are prepared for life beyond the classroom. PISA defines Scientific Literacy as the student's ability to get engaged in science-related issues, and in the ideas and concepts of science, as thoughtful and reflective citizens.

Therefore, scientific literacy requires the development of three competencies: "Explain phenomena scientifically" (recognize, offer and evaluate explanations for a range of natural and technological phenomena); "Evaluate and design scientific enquiry" (describe and appraise scientific investigations and propose ways of addressing questions scientifically) and "Interpret data and evidence scientifically" (analyze and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions).

Baez (1971) infers that there is a relationship between the method of instruction and the attainment of objective of teaching to reach scientific literacy. Therefore, teachers try to engage the students in active classroom environment, and use a variety of effective and innovative approaches. However, there are many students that still fail to acquire even the most rudimentary science skills and concepts and so do not become meaningful learners on one hand, and on the other hand these methods might sometimes fail to really capture the interest of some students.

Science educators around the world consider that inquiry based learning as the best practice for fostering students' interest and understanding in science Yip (2001) and (Rennie 2010).

## 3. Inquiry Based Learning

Inquiry-based learning (IBL) approaches might be effective in helping students to acquire and practice scientific process skills. The *National Science Education Standards* (1996) defines scientific inquiry as diverse ways in which scientists investigate the natural world and propose explanations based on evidence. It involves means to understand science and how scientists work.

According to the NRC Framework document, and Flick and Lederman (2006) inquiry approaches usually involve eight essential aspects:
1) Posing a scientific question or problem to be solved, that physically, mentally, and personally engages the student
2) Suggesting possible solutions
3) Formulating a hypothesis to investigate
4) Designing an action plan and carrying out the procedures of the investigation
5) Observing, gathering, and recording evidence and data
6) Drawing appropriate explanations from the evidence collected
7) Connecting the explanation to previously held knowledge
8) Communicating the conclusions, and explanations through argumentation.

In their article entitled The Many Levels of Inquiry, Banchi and Bell (2008) outline four levels of inquiry. All the levels include the same outline: identification of the problem and the research question, designing the procedure, implementing and assessing the procedure to answer the research questions. And within those steps, students acquire and practice all the scientific skills. According to the authors, teachers should start their inquiry instruction at the lower levels and move up to open inquiry so students develop their skills progressively. The difference between the levels of inquiry is mainly between the role of the teacher and that of student. Table 1 represents the four inquiry levels.

**Table 1:** Inquiry based learning levels

| Levels of inquiry | Problem | Procedure | Solution |
|---|---|---|---|
| Level 1 confirmation | Teacher | Teacher | Teacher |
| Level 2 structured inquiry | Teacher | Teacher | Student |
| Level 3 guided inquiry | Teacher | Student | Student |
| Level 4 open inquiry | Student | Student | Student |

### 3.1. Studies about IBL

Many worldwide studies were performed about inquiry-based learning. ERGÜL et al (2011) in Turkey found that the use of inquiry based teaching methods significantly enhances students' science process skills and attitudes. Also, Şimşek and Kabapınar (2010) in Turkey found that inquiry-based learning had a positive impact on students' conceptual understanding and scientific process skills. Moreover, Timothy (2013) in Columbia found that inquiry-based investigations help children gain insight into their own learning through the development of collaboration skills, perseverance, critical thinking and problem-solving strategies. In addition, Chu et al (2008) in Hong Kong investigated the use of inquiry activity, and the results were very positive with the increase of students' attitudes and interest in learning. Similarly, Abdi (2014) in Tehran found that students who were instructed through inquiry-based learning achieved higher score than the ones which were instructed through the traditional method.

### 3.2 Inquiry based learning and scientific literacy

Researchers in science education argued that inquiry-based teaching methods are the best path to achieving scientific literacy (Gormally, Brickma, Hallar and Armstrong, 2009) as they enable students to discuss and debate scientific ideas, and raise their interest and understanding in science (Rennie 2010).

Many studies have investigated the effect of inquiry in science on scientific literacy, in different levels of learning. At tertiary level, the study conducted by Gormally et al. (2009) reported that undergraduate inquiry lab students demonstrated significant gains in science literacy and science process skills compared to students enrolled in the traditional cookbook labs. Moreover, in a study conducted on grade 7 students, Arief and Utari (2015) investigated the correlation between scientific literacy and the implementation of inquiry in science learning with the theme of global warming. The researchers reported an increase of scientific literacy in the domains of competence and knowledge.

However, many research studies that have investigated the efficacy of inquiry-based approaches for fostering scientific literacy (Oliver, McConney, & Woods-McConney, 2019). McConney et al.( 2014), using PISA 2006 data, reported that students with high levels of inquiry-based instruction in their science classrooms performed less well than those who reported lower levels of inquiry. Similarly results were reported by Lau & Lam (2017), Jiang and McComas (2015) and Areepattamannil (2012) who analyzed PISA data and found that high performance in PISA is related with "low level" inquiry, as structured inquiry such as conducting activities and drawing conclusions from data, rather than "higher level" inquiry such as designing the investigation or raising their own questions.

## 4. Research Problem

The objectives of the Lebanese curriculum emphasize on memorizing facts, concepts, and knowledge, and there are only few objectives that address scientific process skills and meaningful learning (National Center for Educational Research and Development, 1997).

Bou Jaoude (2002) investigated the balance of scientific literacy themes in the Lebanese curriculum. He found that the curriculum emphasizes the knowledge of science" (Aspect 1), "the investigative nature of science" (Aspect 2), and the "interactions of science technology, and society" (Aspect 4), and neglects "science as a way of knowing". The author claimed that teaching strategies, assessment and also the textbooks should be considered when examining scientific literacy. In this vein, Chatila (2016) considered also that teachers are one of the most important factors that play a key role in promoting scientific literacy.

Lederman (1998) considered that the development of scientific literacy requires teaching and learning science in respect to a view of science that includes three major components: a body of knowledge, the methods of science, and the nature of science (Lederman, 1998).

As mentioned above, the best way to develop students' scientific literacy is the Inquiry Based Learning. It is well noticed that inquiry is not highlighted in the Lebanese curriculum, neither as content, nor as a teaching strategy. However, it can be pointed that the national Biology textbook addresses some problem-solving skills that are similar to level 1 confirmation inquiries, or very few ones that are similar to level 2 structured inquiries. (CRDP, 1997).

This study aims to investigate the effect of scientific guided inquiry based teaching in Biology on the students' scientific literacy.

## 5. Framework

As previously mentioned, Chiapetta, Sethna, and Fillman (1993) proposed four dimensions or themes for scientific literacy: Science as a way of thinking, science as a way of investigation, science as a body of knowledge, and science and its interaction with technology and society.

Halloun and Hestenes (1996) has designed a taxonomy to survey students' views about science in physics using Views About Science Survey VASS. In 2007 the author developed a similar survey VASS for Biology students. The taxonomy probes the views of students about the core-disciplinary aspects of science within two dimensions: the structure of science, the methodology of science and the validity of science. In addition, the taxonomy probes students' views about the metacognitive aspects of science by: the learnability of science, the personal relevance in understanding science and reflective thinking. Table 2 below shows VASS for biology taxonomy (Halloun, 2007)

**Table 2:** VASS for biology taxonomy (Halloun, 2007)

| Aspects | Category | |
|---|---|---|
| Core-disciplinary aspects | **Nature of science and of anticipated student knowledge**<br>-Thinking of Science as generic coherently interrelated conceptions and patterns of thinking including problem solving<br>-Relying on multiple ways to represent the situation in any problem and solve it<br>-Relating scientific concepts by Mathematical representations in meaningful ways and expressing such relationships objectively | |
| | **Connections**<br>-Connecting Science and mathematics<br>-Relying on technology for deploying their knowledge in meaningful ways and novel areas<br>-Relating science to everyone's life | |
| Meta-cognitive aspects | Learning condition | **Locus of control**<br>-Science is learnable by anyone willing to do effort<br>-Achievement depends more on personal effort, self-confidence and perseverance<br>-Studying science is enjoyable, builds confidence and forms a self-satisfying experience |
| | | **Meaningful understanding**<br>-Coming to class with a prepared mind<br>-Seeking information from alternative sources than the textbook<br>-Being tolerant and open to others' ideas<br>-Cooperating with others for knowledge development |
| | **Insightful meaningful learning**<br>-Constructing new subject knowledge and delimiting its scope<br>-Deploying knowledge following purposeful plans<br>-Deploying knowledge in a variety of activities<br>-Continuously justifying and evaluating one's work when done<br>-Looking for the teacher as a mediator of learning<br>-Contrasting and regulate any discrepancy between one's own knowledge and the target scientific knowledge<br>-Using assessment for self-evaluation and regulation | |

This study adopts Chiapetta, Sethna, and Fillman (1993) framework and Halloon (2007) taxonomy of Views about Science Survey VASS, to measure students' scientific literacy. The framework of the study is presented in Figure 1.

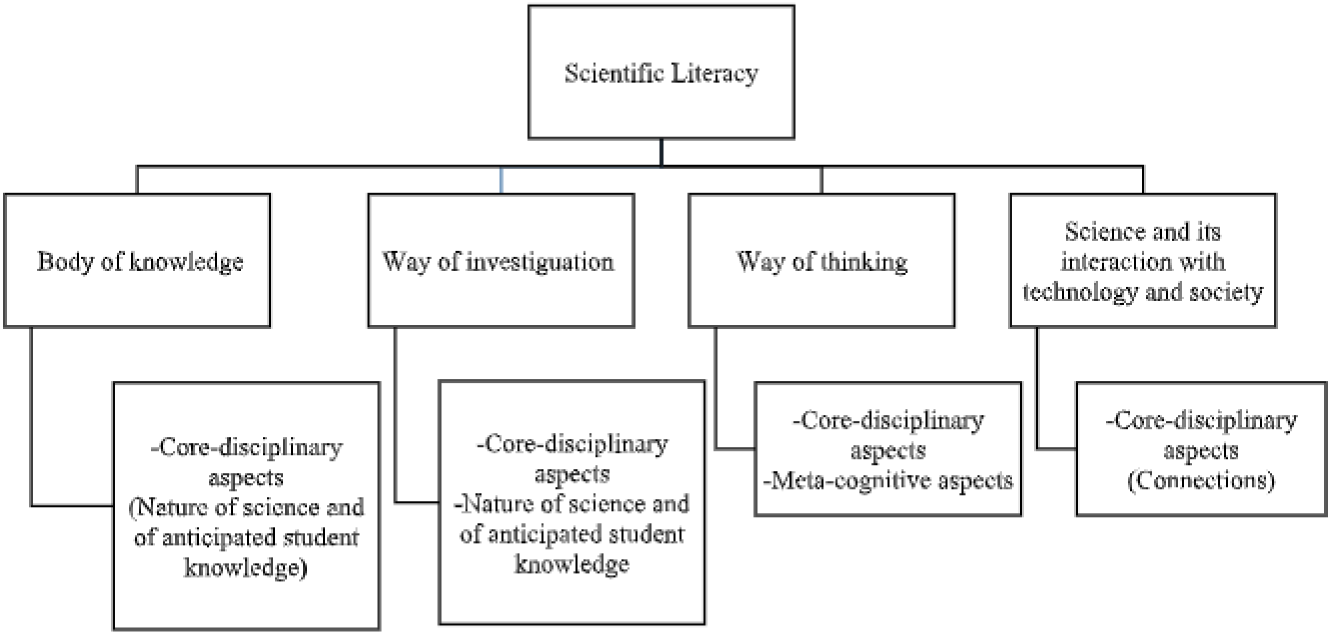


**Figure 1:** The study's framework

Consequently, the following research question is investigated. Does scientific guided inquiry promote scientific literacy by enhancing students'.

- Understanding of the nature of science and of anticipated knowledge?
- Understanding of connections between Biology and other areas?
- Learning conditions including locus of control and meaningful understanding?
- Insightful meaningful learning?

## 6. Methodology

The study employed a quasi-experimental design OXO (observation-intervention-observation), where a group is measured or observed not only after given a treatment, but also before that treatment (Fraenkel et al. 2012). The use of this design is based on the main purpose of this study that is to determine the effect of inquiry based learning on students' scientific c literacy. A sample of 18 grade 10 students participated in the study. All participants were native speakers of Arabic and learning English as a first foreign language. English was the language of instruction in Biology. The same sample was assigned to control and experimental conditions, and an independent variable, the teaching method, was manipulated. The researcher used the pre-test/post-test control group design.

Data was collected by performing VASS "Views About Science Survey" created by Halloun (2007). The survey was used as pre and post-test. It includes 33 multiple choice questions with two viewpoints (a) and (b) on a 5-point scale, and a self-assessment of the student's learning skills. Table 3 shows the number of items for each category.

**Table 3:** Aspects of sciences, their corresponding categories and number of items

| Aspects of science | Categories | Number of items |
|---|---|---|
| Core-disciplinary | Nature of science and of anticipated student knowledge | 8 |
| | Connections | 5 |
| Meta-cognitive | Learning conditions | 11 |
| | Insightful, meaningful learning | 9 |

Descriptive statistics for the pre and post-tests were computed. Inferential statistics were used in order to show any significant progress in the students' pre-tests and post-tests scores and to be able to do a comparison. T-tests were performed to compare and determine whether the population means differ. T-tests determine the p-value that will indicate the significance level. Significance was determined at the 0.05 level.

## 7. Procedure

The duration of the study was 10 weeks. The students were taught 3 Biology periods per week. The procedure included 4 steps.

Step 1 was applied in the first 3 weeks, and was a preparatory period for implementing the study. The aim of step 1 was to help both students and teachers to master the learning strategy used in this study by acquainting the students with classroom norms, procedures, and routines, and modeling the process of scientific inquiry for students with level 1 then level 2 activities followed by introducing level 3 activities. After that, step 2 was applied at week 4 by administering the pre-test. Then, step 3 was applied at week 5, 6, and 7 which was the period of implementing the study, where students were involved in a scientific guided inquiry (level 3) activity.

The topic used was "transpiration in plants" in grade 10 national Biology book. Usually this transpiration topic is

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hard for the students. Only few students would have acquisition, retention of conceptual understanding, and meaningful learning of this concept. That's why this concept was chosen. During the implementation the study, the students were provided by news report which tells about frequent fires. There was a small discussion about the topic in the class. After that the students, guided by the teacher, made a research about the subject, in order to find an article which will help them in their research. The students were then involved in a discussion to set the problem, and formulate hypothesis, that were approved by the teacher. Then the teacher facilitated a class discussion in which the students designed a procedure to answer their research question, which was also approved by the teacher. The teacher acted as a facilitator by asking leading questions and drawing attention to interesting answers. During the experiment, the students identified variables, listed the basic equipment, proposed the procedure, collected data, interpreted the results, and drew out conclusions. Finally, in step 4 at week 8, the post-test was administered.

## 8. Results

### 8.1. Core-disciplinary aspects

#### *8.1.1. The nature of science and of anticipated knowledge*

Table 4 shows the mean scores and standard deviations for students' understanding of the nature of science and of anticipated knowledge in pre-tests and post-tests.

| Test | Mean | S.D. | sig. (T.Test) |
|---|---|---|---|
| pre-test | 3.5 | 0.7 | 0.0005 |
| post-test | 4.1 | 0.4 | |
| Total | 3.8 | 0.7 | |

Sig. T.Test=0.0005 < 0.05

At the level of core-disciplinary aspects of science, in the category associated with the nature of science and of anticipated knowledge, the students' mean scores increased from 3.5/5 in the pre-test to 4.1/5 in the post test. Also, the standard deviation decreased from 0.7 in the pre-test to 0.4 in the post-test. The significance T. Test is 0.0005 which is less than the significance value that is 0.05. These results indicate that the students had more understanding for the nature of science and anticipated knowledge, meaning that there is a significant correlation between inquiry-based learning and nature of science and of anticipated knowledge.

#### *8.1.2. Connections*

Table 5 shows the mean scores and standard deviation for students' connections of science to math, technology and real life in pre-tests and post-tests.

| Test | Mean | S.D. | sig. (T.Test) |
|---|---|---|---|
| Pre-Test | 3.0 | 0.8 | 0.0000 |
| Post-Test | 4.0 | 0.5 | |
| Total | 3.5 | 0.8 | |

Sig. T.Test=0.000 < 0.05

In the category associated with connections of science to math, technology and real life, the students' mean scores increased from 3/5 in the pre-test to 4/5 in the post test. Also, the standard deviation decreased from 0.8 in the pre-test to 0.5 in the post-test. The significance T. Test is 0.0000 which is less than the significance value that is 0.05. These result indicate that the students connected science more to math, technology and real life, meaning that there is a significant correlation between inquiry-based learning and connecting science to math, technology, and real life.

### 8.2. Metacognitive aspects

#### *8.2.1. Learning conditions*

Table 6 shows the mean scores and standard deviation for students' learning conditions in pre-tests and post-tests.

| Test | Mean | S.D. | Sig. (T.Test) |
|---|---|---|---|
| Pre-Test | 3.2 | 0.6 | 0.0000 |
| Post-Test | 4.0 | 0.4 | |
| Total | 3.6 | 0.6 | |

T. Test=0.0000 < 0.05

At the level of metacognitive aspects of science, in the category associated with the learning conditions, the students' mean scores increased from 3.2/5 in the pre-test to 4/5 in the post test. Also, the standard deviation decreased from 0.6 in the pre-test to 0.4 in the post-test. The significance T. Test is 0.0000 which is less than the significance value that is 0.05. These results indicate that the students' learning conditions has improved among the students, meaning that there is a significant correlation between inquiry-based learning and learning conditions.

#### *8.2.2. Insightful meaningful learning*

Table 7 shows the mean scores and standard deviation for insightful meaningful learning in pre- and post-tests.

| Test | Mean | S.D. | sig. (T.Test) |
|---|---|---|---|
| Pre-Test | 3.2 | 0.8 | 0.0000 |
| Post-Test | 4.1 | 0.6 | |
| Total | 3.6 | 0.9 | |

Sig. T.Test=0.0000 < 0.05

In this category, he students' mean scores increased from 3.2/5 in the pre-test to 4.1/5 in the post test. Also, the standard deviation decreased from 0.8 in the pre-test to 0.6 in the post-test. The significance T. Test is 0.0000 which is less than the significance value that is 0.05. These results indicate that the students showed more insightful meaningful leaning, meaning that there is a significant correlation between inquiry-based learning and insightful meaningful learning.

## 9. Discussion

The results show significant changes between the pre and post tests for each VASS categories. The students' development of the core-disciplinary aspects has increased where they have a positive effect on the students 'acquisition and practice of nature of science skills and understanding of anticipated knowledge and are able to connect between different areas of science and with Math, technology, and real life.

Also, the students' development of meta-cognitive aspects has significantly increased, where students learn science with considerable understanding, build/formulate new knowledge by modifying and refining their current understanding, explain a scientific event or observation, and answer on questions about the world based on evidence.

Therefore, the guided inquiry fostered the development of the students' metacognitive as well as core-disciplinary aspects of science, which means that the students' perspectives of science has increased at the level of way of thinking, way of investigation, body of knowledge and science and its interaction with technology and society, and thereby promoting the development of scientific literacy.

The significant differences between the pre-test and the post-test may be attributed to the practice of levels 1 and 2 of inquiry-based learning, before the implementation of the study, that include solving problems using the scientific method, transferring the amount of responsibility of inquiry activities to the students, scaffolding the inquiry instruction, asking powerful guiding significant questions, making formative assessment frequently, and practicing different skills.

The findings are in parallel with the literature review, namely the reported studies that confirm a significant correlation between guided inquiry learning approach and scientific literacy ( Arief and Utari ,2015; McConney et al., 2014).

## 10. Conclusion

The study aims to investigate the effect of guided inquiry learning on scientific literacy. The latter was measured by VASS survey, as illustrated in figure 1. In this study, the teacher trained the students for 3 months on practicing levels 1, and 2 inquiry activities in the classroom before the study. Then, the study was implemented by applying level 3 inquiry activity with the students.

The results of our study present evidence that scientific guided inquiry teaching method improves the students' scientific literacy dimensions.

The study applied guided inquiry approach on a small sample, which means that the results cannot be generalized, and more research is needed to be done for a larger sample and using different levels of inquiry.

If teachers encourage the practice of inquiry-based learning in the classroom and explicit instructions for inquiry-based learning are highlighted in the curriculum and included in biology/science national textbooks as procedural and situational knowledge, there will be a better educating of students that emphasizes on growing metacognitive and core-disciplinary aspects of learning in students who will be scientifically literate, better citizens, and life-long learners of science.

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