A comparative study of the effectiveness

of the 'History of Science' approach and 'Socio-scientific Issue' approach

on developing high school biology students' understanding

of the nature of science.

by

CHAN, Hon Yuen

A Thesis Submitted to

The Education University of Hong Kong

in Partial Fulfillment of the Requirement for

The Degree of Doctor of Education

September 2019

Statement of Originality

I, CHAN, Hon Yuen, hereby declare that I am the sole author of the thesis and the thesis and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no materials in this thesis has been submitted for a degree in this or other universities.

Abstract

The aim of this study was to compare the effectiveness of two teaching approaches for senior secondary biology students to learn about the nature of science (NOS): the History of Science (HOS) approach, which is the most commonly used approach in Hong Kong schools, and the Socio-scientific Issue (SSI) approach, which develops students' understanding of NOS through analysis of socio-scientific issues. This study was motivated by the consistent reports by the Hong Kong Examinations and Assessment Authority (HKEAA) on the poor performance of Grade 12 Biology students in the Hong Kong Diploma of Education Examination (HKDSE) regarding their understanding of the Nature of Science (NOS). From the literature, the SSI approach presents a viable alternative in improving students learning of NOS. Three research questions were construed. 1) Could the SSI or HOS approach enhance Hong Kong senior secondary students' understanding of major tenets of NOS? 2) Which approach, SSI or HOS, could help Senior Secondary Biology students develop more informed conceptions of major NOS tenets? 3) Are there any influences of gender or biology performance on students' learning of NOS using either approach?

This research was based on a quasi-experiment design. The sample consists of 67 secondary students from four intact classes, two of which were biology classes at Grade 11 and two biology classes at Grade 12. They were divided into two treatment groups (HOS and SSI), with each group comprising one Grade 11 and one Grade 12 class. All students received a pre-test consisting of 10 open-ended questions based on the Views of Nature of Science form D+ (VNOS-D+) instrument to test students' understanding of NOS before the intervention. After this, both groups went through a 3-day learning process to enhance their understanding of NOS. The only difference was that one group was taught through the HOS approach, while the other group received the intervention by using SSI. After almost two weeks of the intervention, all

participants completed a post-test exactly identical to the pre-test. Some of the participants were invited for a semi-structured interview to elicit further information about their concepts and ideas about NOS as revealed in their post-test. The quantitative data from the post-test and pre-test for the two treatment groups were analyzed by paired *t*-tests independently, so as to test whether each of the two teaching approaches could improve the learning of NOS. The performance of the two treatment groups were also compared using ANCOVA, with the pre-test result as the covariate, to analyze the difference of the two groups in their improvement, if any, from post-test to pre-test. This was to determine the effect of HOS and SSI teaching approaches on post-test test score after controlling for the pre-test test score.

The findings of the paired *t*-test showed that there was statistically significant difference between the pre-test and post-test test score after intervention using either teaching approach, which means that both approaches were able to improve students' NOS concepts. However, there was no statistically significant difference between the two approaches in improving students in learning of NOS. There was no interaction between the teaching approaches and students' gender or general biology achievement as shown by the two-way ANCOVA. Despite this, analysis using Pearson's correlation showed that higher achievers performed better regarding the NOS tenet of theory & law than lower achievers in the HOS group but not the SSI group.

The qualitative data obtained from the VNOS-D+ post-test were analyzed to reveal hints for the reason why an approach was successful or not, thus revealing the missing link in the whole picture. The qualitative data from the post-test and semi-structured interview revealed that more students in the HOS group tended to believe in "knowing is seeing", which may contribute to the rejection of the tenet of creativity & imagination in the post-test questionnaire.

Both treatment groups displayed only a partial understanding of the NOS tenet of subjectivity. Students of the HOS group made more reference to historical cases as evidence to support their assertions or arguments across different NOS tenets. By contrast, students of the SSI group seemed to show a greater tendency to use more recent issues or examples to substantiate their own claims. However, the SSI group appeared to use more examples from previous learning or their biology lessons than the HOS students to explain the tenets of NOS. These inferences drawn from the VNOS-D+ questionnaire were also supported by the findings of the semi-structured interview.

To conclude, both teaching approaches were able to improve students in learning the concepts of NOS, but the HOS group seemed to play down the tenet of creativity & imagination and SSI students seemed to support the claim with examples related to SSIs. It also appeared that the HOS approach was able to help high achievers to learn the tenet of theory & law more effectively. There were implications from this study. Both of the SSI and HOS approach may be appropriate for improving students learning of NOS in the current Hong Kong context. Based on the inherent strengths and weaknesses of both teaching approaches revealed by the present study, it is suggested that the two approaches may complement each other in developing students' understanding of NOS, such that educational practitioners may use them simultaneously to deliver the concepts of NOS to Hong Kong students.

Keywords: History of Science, Socio-scientific Issues, Nature of Science

Acknowledgements

I would like to acknowledge the many people who had supported and encouraged me over these years since 2012 and to whom I am forever grateful. First, I would like to thank my wife, Eubre LAM. She took care of my three little children since I took the program of Doctor of Education (EdD), especially in the last few years. I needed to leave them alone to work on my dissertation. I could not stay with her at the time when my children were growing up. I am grateful for her unconditional love.

I am eternally grateful to Mr. James WARJRI for his help with proofreading my essay for application for the EdD program. He was the first colleague that knew my applying for this program. During those years of studying, he kept encouraging me and helped taking care of my family. My friend, Dr. Ziv CHEUNG, also initiated my heart to struggle for a higher degree in education. We enrolled in this program together, and had spent our time together during the lesson, assignment, and dissertation, but he completed this program earlier than me. I would like to thank him for his help in translating the questionnaire from English into Chinese. For the questionnaire, I would like to thank Dr. Norman LEDERMAN, during my despair about the VNOS-D+, for teaching me how to use the questionnaire and interpret the result with the use of the rubrics. For all the teaching materials, which I prepared for the study, my thanks go to Dr. Chi Chiu CHEANG and Dr. Wai Chin LI, both from the Education University of Hong Kong, who were introduced to me by my thesis supervisor, Dr. Yeung Chung LEE. Although we did not know each other, Dr. Cheang and Dr. Li still worked as my external reviewer to go through all my teaching materials and provided suggestions to me. Thank them so much.

Prof. Yau Yuen YEUNG, my associate supervisor, brought to me the concept of research design while attending his course. When I was stuck at the choice of appropriate data analysis methods, he gave me timely advice. I would like to thank him for his help and all the inspirations provided to me about data analysis. And lastly, my gratitude goes to Dr. Yeung Chung LEE whose expert mentoring was the key to my success during this process. The expert knowledge he brought to our conversations about both research and the writing of my dissertation proved invaluable to me. I am really grateful for his support during this process. My research could not be completed without his encouragement, which pushed me to accomplish. I truly could not have accomplished all these without his unfailing support. I feel sorry if my dissertation might have, in any way, interfered with his retirement life.

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List of Abbreviations

CDC	Curriculum Development Council
EDB	The Education Bureau of Hong Kong, SAR
HKEAA	Hong Kong Examinations and Assessment Authority
HKDSE	Hong Kong Diploma of Secondary Education Examination
HOS	History of Science
NOS	Nature of Science
SSI	Socio-scientific issue
VNOS	Views of Nature of Science

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1 Introduction

1.1 Introduction

The concept of the NOS occupied an important status in scientific literacy, but there have been no unified description of the components or tenets of NOS. In this study, seven tenets that are commonly used in this field were adopted as criteria for studying the effectiveness of two different teaching approaches on the improvement of students learning of NOS. In the Hong Kong science curriculum, NOS tenets are also described that match up with those adopted in this study to a considerable extent. Although the new senior secondary science curriculum in Hong Kong has already been implemented for 10 years since 2009, the HKDSE examiner reports consistently indicated that there was no improvement in students' examination performance for the questions that assessed their understanding of NOS. It was hoped that this study could propose suggestions based on empirical findings to improve Hong Kong senior secondary biology students in learning NOS, and hence their examination performance on those questions.

1.2 Statement of the Problem

1.2.1 Curriculum policy about the teaching of NOS in Hong Kong

Implementation of NOS education in Hong Kong was largely motivated by the trend of international science education to include NOS toward 1990s, as exemplified by the work done by the American Association for the Advancement of Science and National Research Council. However, the discussion on NOS in Hong Kong almost lagged behind for a decade. According to Tao (2003), there had not been any inclusion of NOS tenets in the Hong Kong Science curriculum before 2000, although some of them were informally embedded in the curricula aims. Nonetheless, students did not receive a formal and structured teaching about NOS in school science subjects. The Curriculum Development Council of Hong Kong revised the Secondary 1-3 (Grade 7-9) Science curriculum in 1998 (HKCDC, 1998) and implemented the curriculum in September 2000. The first topic of the science curricula was "What is Science?". This topic included scientific investigation skills, such as making observation, formulating hypotheses, designing and performing experiments, analyzing data and drawing the conclusion. The scope and limitations of science were also hinted at when referring to the need for fair test and control of variables (Yip, 2006). For the senior level, Secondary 4 to 5 (Grade 10-11), the revised curricula of NOS in physics, chemistry and biology were implemented after three years of implementation of the curricula for junior forms. The aims and contents of NOS were expected to be implemented throughout the senior level.

1.2.2 Current situation of NOS learning in Hong Kong

Following the curriculum reform launched in September 2009, the period of senior secondary education was shortened, from 2 + 2 years to 3 years. Previously, it was 2 years for Certificate Level of Secondary 4 and 5 (Grade 10-11), and 2 years for Advanced Level (Pre-University), i.e., Secondary 6 and 7 (Grade 12-13). After the reform, there is no distinction between certificate and advanced level, and the two progressive levels were combined into a single level – the Hong Kong Diploma of Education – spanning three years. As a result, the curriculum was reconstructed into the new format, and the syllabi for science subjects also were reformed. According to the Biology Curriculum and Assessment Guide (CDC & HKEAA, 2007), the aims of the Biology curriculum were to allow students to understand the nature of scientific inquiry in biology and reinforce their understanding of the nature of science in biology related context. The Hong Kong Education Bureau prepared a set of teaching materials, namely *Curriculum Resources for Infusing Ideas about Nature and History of Biology and Scientific Inquiry into the Learning and Teaching of Senior Secondary Biology Curriculum* published in 2009, which focuses on teaching NOS through cases extracted from the history of science (HOS) and discoveries in biology, such as the first vaccine discovery, discovery of the cause of gastric ulcer, etc. Moreover, it was expected to help students to understand observation, formulating hypotheses, experimentation and analysis as the processes for developing science knowledge, as well as to understand the nature and limitations of scientific activities.

For the teaching of NOS, the textbook was the main vehicle to deliver the concepts of NOS. Two popular junior science textbooks," i-Science 1A" and "Interactive Science 1A", and two popular senior secondary biology textbooks, "HKDSE biology concepts and application 1A" and "New senior secondary Mastering biology 1A" were reviewed about the contents including concepts and ideas of NOS, and the ways they are delivered to students.

First, "i-Science 1A" written by Yip (2011), is a science textbook for junior secondary students to learn science. The NOS concept is arranged in the first page of the first chapter - "Introducing Science". There is a double-page cartoon displaying how scientists identified the fossil of part of a dinosaur. Scientists made some guesses based on the discovered fossil records, such as tooth, horn or spike. The textbook poses questions – "Why do scientists have different ideas?" "How did they collect evidence to support their ideas?" - to stimulate students to think. In the teacher's guide to the textbook, there are many notes for guiding teachers to use this story to deliver the concepts of NOS to students. First, teachers should ask students to guess which part of the dinosaur the fossil record discovered belongs to. This allows them to raise different ideas and disagree with each other. The teacher is supposed to guide students to find out more evidence to support their ideas by conducting inquiry, which underscores the tenet of empirical basis. The teacher was also supposed to guide students to interpret data based on their background knowledge and experience. From students' differences in interpreting the same set of data based on their different views of the finding, the tenet of subjectivity could be generalized. Furthermore, the teacher is supposed to raise the issue of technology advancement, such as carbon-14 dating, which has provided scientists with new insights into the geological time span of the fossil records. However, all the teaching notes were only accessible to the teacher only. This cartoon appears in the first page of the chapter, before the content, as an introducing page to arouse the interest of students to think about this chapter.

In chapter one, there are five topics, "Introduction to science", "Safety in the laboratory", "Laboratory apparatus and practical skills", "Measurements in scientific study", and "Conducting a simple scientific investigation". For the simple scientific investigation, which focuses on the five steps of scientific method - making observation, asking a question, suggesting a hypothesis, testing the hypothesis, and drawing a conclusion. Those five topics occupy 51 pages, but the cartoon with implicit NOS concepts occupies two pages only, serving merely as a prelude to the subsequent detailed treatment of the stepwise scientific method. As a matter of fact, this stereotypical perception of the scientific method as a stepwise procedure is contradictory to the common understanding by the science education community (McComas, 2004). There were no NOS concepts explicitly and implicitly mentioned in those topics.

For "Interactive Science 1A" (Tong, Ip, Lam and Wong, 2010), another junior science textbook. The first chapter is "Introducing Science". There were five topics, "What is science?", "The science laboratory", "Basic experimental skills", "Making measurements", and "Simple scientific investigation". There was no cartoon or statement to describe the concepts of NOS.

There are five topics in chapter one, which are “What is science?”, “The science laboratory”, “Basic experimental skills”, “Making measurements” and “Simple scientific investigation”. The first topic, “What is science?”, shows how scientists work so as to point out the importance of observation, and discuss how to use the five senses to make observation. However, there is no further discussion about the difference between observation and inference, nor the other tenets of NOS. For the topic of “Simple scientific investigation, it also describes the five steps of the scientific method as in the first textbook (Yip, 2011). These include identifying the problem to be investigated, making a hypothesis, designing an experiment, carrying out the experiment, and drawing a conclusion. No tenets of NOS could be found in those topics. Compared to the previous textbook, this textbook is even weaker as students are not motivated to learn about the tenets of NOS.

The Biology textbook - “New Senior Secondary Mastering Biology – 1A” - written by Yung, Ho, Ho, Tam & Tong (2009), was designed for senior secondary levels. This was revised from a previous version according to the new Biology Curriculum and Assessment Guide (HKEAA & CDC, 2007). The first topic is “Introducing biology”, covering six topics: “What is biology?”, “The characteristics of organisms”, “How do scientists study biology?”, “Why should we study biology?”, “Major biological discoveries and inventions”, and “An outline of this book”. The concept of scientific method is introduced under the topic of “How do scientists study biology?”. This topic describes the scientific method as comprising six steps, one step more than the junior science textbooks. These six steps are making observations, asking a question, proposing a hypothesis, making a prediction, doing experiments and drawing a conclusion.

Additionally, on the last page of this chapter, there is an article for students to read by themselves - “Do organisms arise from non-living things?” This article describes the steps of the experiment conducted by Louis Pasteur to prove microbes were present in dust particles floating in the air. At the end, several questions are posed to students. One of the questions asks students to state the one characteristic of the development of scientific knowledge. However, throughout the whole chapter, no ideas or concepts of NOS are explicitly mentioned, such that it appears difficult for students to learn the tenets or concepts of NOS. Nevertheless, there are some teaching tips for teachers to teach the concepts of NOS. These include the ideas that scientific knowledge is tentative and subject to change, and that science is affected by the technology and equipment available at the time. As in the other textbooks mentioned above, those sentences were accessible by teachers only. If teachers do not mention about them, students will not be able to learn those concepts. Moreover, from the arrangement of the content on the last page of this chapter, it looks as if it is intended to be an extension for students to learn, rather than a compulsory part, which is likely to be skipped by students and teachers.

NOS concepts are found to be embedded in the next chapter, which discusses the cell theory. This chapter talks about how the scientist's discovery of cell was made possible by the advancement of technology and the collective efforts of scientists. However, the concepts of NOS such as creativity and imagination, as inferred from the observation and human endeavour in relation to the development of microscope and the discovery of cell, could only be found in the teacher guide. Although teachers were expected to mention explicitly those concepts explicitly during the lesson, the concepts of NOS appeared in the textbook are implicit. The second chapter on cell membrane also displays concepts of NOS in the teacher's notes to guide the teacher to introduce the development of models including tentativeness, and reasonable scepticism. But again, they were not printed in the students' version, such that students will not be able to access those concepts if teacher skips this part. Overall, this textbook delivers the concepts of NOS only in an implicit manner through the history of scientific discovery, yet stopping short of explicitly showing the concepts of NOS in the student's textbook.

In the second biology textbook, "HKDSE Biology concepts and applications 1" (Chan, Fung, Li, Ng & Sy, 2014), there are three topics in chapter one to introduce biology: "What is biology?", "The importance of biology to humans" and "How can we study biology?". The scientific method comprising four steps is mentioned in the topic of "how can we study biology?". These four steps are "observing and asking questions", "proposing a hypothesis", "designing and performing experiments" and "analysing results and drawing a conclusion". Making prediction is absent compared with the previous biology textbook (Yung et al., 2009). There was a paragraph on the limitation of science, which points out the idea that scientific conclusions remain tentative and subject to revision if new evidence appears. Only this single tenet of NOS explicitly appeared in this paragraph. There is also an article describing how the theory of spontaneous generation by Louis Pasteur was generated with the experimental steps he designed (Yung et la., 2009). However, there is a lack of printed content for students and teachers' notes about the tenets of NOS.

In the next chapter about cellular organization, there is a paragraph describing the development of the microscope and discovery of the cell. As in the previous textbook, the NOS ideas are only displayed for teacher only, including the ideas that "scientific knowledge is based on observation of the natural world", "science is a process of ongoing inquiries", and "science is affected by the technology and the types of equipment available at the time". Again as in the other textbooks there is no printed content in the students' textbooks. These ideas only appear in the teacher's guide including tentativeness, and creativity and imagination in the production of scientific models. In summary, this textbook is aligned with the previous ones in that NOS ideas are only embedded implicitly in historical stories to communicate about how scientists work. No explicit descriptions in the form of printed paragraphs or sentences are available in the students' texts. Hence, if the teacher skips this part, students may not be able to learn the concepts of NOS by self-study or lesson preparation.

To conclude, these junior science and senior biology textbooks were revised after the launching of the new curriculum, with the concepts of NOS embedded. However, such concepts are mostly communicated implicitly. They are mostly hidden in the historical stories about how the scientists works, and no clear definitions of NOS tenets are printed in the student version of the textbook. They are only printed in teacher version of the textbook in the form of teaching notes for teachers only. It is doubtful whether this is an effective way to deliver NOS concepts to students. Arguably, if the concepts of NOS are printed in the student's textbook, students may learn those concepts independently during their self-study, or revision before examination or test.

1.2.3 Current situation of NOS assessment in Hong Kong

All sixth-form biology students participated in the public examination, the Hong Kong Diploma of Secondary Education (HKDSE) examination administered by the Hong Kong Examinations and Assessment Authority (HKEAA) starting from 2012 after the curriculum reform and implementation in September 2009. Questions explicitly related to the nature of science had been set in examination papers from 2013 to 2018.

According to the HKEAA HKDSE Biology Examination reports from 2013 to 2018, Hong Kong students performed poorly in the questions related to NOS. The common weaknesses of the candidates were that they failed to understand the idea that scientific models require the input of imagination, and to describe how observations were guided by prior knowledge and understanding (HKEAA, 2013; HKEAA, 2014; HKEAA, 2015). In 2016, the comment from the examination report was fair. It claimed that candidates often provided the answers with the aspects of NOS that were adapted from previous examinations, such as “Science is evidence based”, “Doing science requires imaginations / creativity”, “Scientific knowledge is tentative and subject to change”, “interpretation of observations is guided by our prior understanding of other theories and concepts”, “Science is based on evidence”, “Science knowledge is tentative and dynamic”, “Science is socially and culturally embedded”, etc. The question in the examination cites the process of experimentation conducted by scientists to find out where the genetic information was stored inside the eukaryotic cell, and how other scientists developed and tested another hypothesis based on the first experiment’s result. Students were asked to draw the conclusion from the experimental result and give one aspect of NOS as reflected by the whole experiment. However, the candidates could not cite relevant information from the question about the series of experiments as supporting evidence. The report also suggested that teachers used the teaching package produced by the Education Bureau to teach NOS to students, implying possible non-compliance with the official guides, or misuse of those guides (HKEAA, 2016). In 2017, again the comment from the examination report was that the questions on NOS were poorly answered. It claimed that only a small proportion of candidates were able to point out that scientists were skeptical and ready to accept results that were contrary to previous beliefs, and also many candidates simply stated the answers, which appeared in previous examinations (HKEAA, 2017). In 2018, the HKEAA’s comment was consistently poor. The question provided two scientists’ ideas about the evolution of the long-necked giraffe, which was the historical story appeared in the curriculum. First, students were asked to elaborate the view of scientists on the evolution of the long-necked giraffe, based on their current knowledge about evolution. Next, the question stated the idea of humans evolving from common ancestors along with other species was not accepted by many people, since it was opposed to their religious belief. Students were asked what implication could be drawn from this sentence about NOS. Only 32 % of candidates correctly stated that science could be affected by cultural or religious factors (HKEAA, 2018). This implied that most of them did not have a clear picture of this particular NOS tenet.

In almost three decades ago, there were many researchers reporting that an appropriate way to teach NOS was by introducing successful practices adopted by scientists to students through an explicit historical approach. Students could then know the way scientists' think, hence allowing students to develop the knowledge of NOS (Bybee, Powell, Ellis, Giese, Parisi & Singleton, 1991; Solomon, Duveen, Scot & McCarthy, 1992). Monk and Osborne (1997) produced a prototype for teachers to improve students learning of scientific content knowledge and NOS by embedding the HOS into the lesson. In most research studies, results consistently shown that the HOS approach was an effective way for teaching and delivering NOS concepts in the lesson to students (e.g. Abd-El-Khalick & Lederman, 2000; Allchin, 2012; Hottecke, Henke & Riess, 2012; Lin & Chen, 2002; Rudge & Howe, 2009; Rudge, Cassidy, Fulford & Howe, 2014; Wahbeh & Abd-El-Khalick, 2014). It was perhaps with such evidence in mind that, the HOS approach in the form of telling stories of scientific discoveries were selected as the approach for teaching NOS in Hong Kong Secondary Science curriculum.

However, some recent researches hinted that historical approach might not be the best way to deliver NOS to students. It might just assist students in understanding the empirical, observation and inference, creative and subjective tenets, while ignoring the other tenets of NOS, such as the social and cultural tenet (Abd-El-Khalick & Lederman, 2000; Fouad, Masters

& Akerson, 2015). By contrast, socio-scientific issues (SSI) have been found to be an effective tool for students to develop scientific literacy, such as consensus building, moral reasoning, evidence-based argumentation, and application and understanding of science content knowledge by developing processes that contribute to knowledge construction (Sadler, 2009). Moreover, some researches claimed that using SSI to teach NOS was significant for students in learning NOS (Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum & Callahan, 2009).

1.3 Purpose of the Study

The curriculum reform in Hong Kong have been implemented for almost a decade with the suggestion to use HOS as the main approach to deliver the concept of NOS to secondary students in the science curriculum. However, according to the HKDSE examination reports, which showed that the performance of students in the question related to NOS was consistently not up to expectation (HKEAA, 2013; HKEAA, 2014; HKEAA, 2015; HKEAA, 2016; HKEAA, 2017; HKEAA, 2018). Their major weakness was the lack of clear concepts and rationale for those tenets of NOS. Students only remembered the name of tenets, but failed to understand the underlying rationale. Some previous research articles exposed the weakness of using HOS to deliver the concept of NOS (Abd-El-Khalick & Lederman, 2000; Fouad, Masters & Akerson, 2015), and more research papers suggested that SSI could be an effective tool for students to develop the senses and concepts of NOS (Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Sadler, 2009; Zeidler et al., 2009). To the best of my knowledge, there were no researches that compare the HOS and SSI approach in facilitating Hong Kong Senior Secondary Biology students learning of the concepts of NOS. This study aims to compare the effectiveness of the two teaching approaches for senior secondary biology students to learn about the NOS.

The research questions were as follows:

(1) Could the SSI and HOS teaching approaches enhance Hong Kong senior secondary students' understanding of the major tenets of NOS?

(2) Which approach, the SSI approach or HOS approach, is more effective in helping Senior Secondary Biology students develop more informed conceptions of the major NOS tenets?

(3) Are there any influences of gender or biology performance on the students' learning of NOS using either approach?

1.4 Significance of the Study

This study was motivated by the persistent problem of under-performance of HKDSE biology candidates in answering questions on various aspects of NOS over the years since the incorporation of NOS learning into the senior secondary biology curriculum. It aimed specifically to further examine the effectiveness of the HOS approach as the sole approach recommended by the Hong Kong science and biology curriculum planners. It examined the possibility of introducing the SSI approach as an alternative teaching approach to HOS to deliver the concept of NOS to senior secondary biology students. It also sought to compare which approach is more effective in developing understanding of NOS among senior secondary biology students through two sets of activity and instruction specially designed for realizing these two approaches in the HK secondary biology classroom setting. Hopefully, the findings could help to clarify the effectiveness of the HOS approach as an officially recommended teaching approach for teaching NOS and explore the effectiveness of the SSI approach as a viable alternative to the HOS approach. The effectiveness of these two alternative approaches will be considered in terms of their relative strengths and weaknesses in comparison with each other. It was hoped that the findings of this study could provide insights into potential improvement measures for teaching and learning NOS, which has so far been a relatively problematic and neglected topic in biology education in Hong Kong. These measures might include ways to further develop the existing local science and biology curricula, teaching approaches and instructional practices, as well as assessment.

1.5 Organization of this thesis

This thesis is divided into five main chapters, with a list of references and relevant appendices attached at the end.

1.5.1 Chapter One - Introduction

Chapter One – Introduction - describes what problems we are facing students in Hong Kong after the reform of the science curriculum by the Curriculum Development Council (CDC) since 2009 (CDC & HKEAA, 2007). This research focused on the problem that students had not been able to meet the requirements of the science curriculum with regard to the learning of NOS as indicated by the consistent unsatisfactory results in the HKDSE (HKEAA, 2013; HKEAA, 2014; HKEAA, 2015; HKEAA, 2016; HKEAA, 2017; HKEAA, 2018). From literature, many research articles showed that both the HOS (Abd-El-Khalick & Lederman, 2000; Allchin, 2012; Hotteche et al., 2012; Lin & Chen, 2002; Rudge & Howe, 2009; Rudge et al., 2014; Wahbeh & Abd-El-Khalick, 2014) and SSI (Khishfe & Lederman, 2006; Walker & Zeidler, 2007; Sadler, 2009; Zeidler et al., 2009) teaching approaches could effectively deliver NOS to students in science studies. However, there was not a single research that compares both of these two teaching approaches in Hong Kong, not to mention for the teaching of NOS in the new senior secondary Biology Curriculum. This research aimed to address this problem by comparing the effectiveness of both approaches in improving students' understanding of NOS and identifying any influences on students' learning of NOS using either approach. The methodology including the sampling method, research design, and research instruments used in this research was also introduced throughout this chapter.

1.5.2 Chapter Two – Literature Review

Chapter Two - Literature Review – presented the result of a detailed literature review that led to the framing of the research questions of this study, and displayed the tenets of NOS as discussed worldwide over a very long time with no unified conclusions (McComas & Olson, 1998). Amongst these, McComas (2005) suggested nine tenets of NOS after extensive and qualitative analysis of 23 books; Alshamrani (2008) performed a meta-analysis based on 14 journal articles and concluded 12 tenets of NOS; and Bartos & Lederman (2014) concluded the definition of NOS from literature reviews, underscoring seven tenets. There were some similarities and differences in the tenets proposed by various authors. After a comprehensive literature review, a set of tenets of NOS were selected and adopted for this study based on three considerations. First, these tenets shared similarities with most of those advocated by NOS researchers; second, they were closely aligned with those included in the Hong Kong curriculum; and, third, they are tenable to measurement by well-validated instrument found in the literature.

The HOS approach, which was the existing approach adopted by the HK curriculum, was reviewed in this chapter to examine their effectiveness as a teaching approach. For instance, Abd-El-Khalick & Lederman (2000) reported that it was difficult to embed the concepts of NOS in the course of teaching to influence students. They suggested that historical episodes or materials might be limited to allow students to be exposed to the conceptual shift from the history of science to learning science. Yip (2006), however, suggested that using the historical method to teach NOS was effective, since it could provide concrete examples or stories to students by showing how science works, and the thinking of early scientists was found to be similar to the unconscious reasoning of students. Also, episodes that depict the evolution and revolution of scientific knowledge could pose great mental challenges to students.

Wolfensberger and Canella (2015) discovered that students showed more informed interpretations of several concepts of NOS, such as, theory-laden, social-cultural embeddedness, and tentativeness after learning through HOS. This showed that the HOS approach might improve the understanding of some tenets of NOS in secondary students. To make the literature more confusing, Tao (2003) found that the HOS teaching approach failed to inculcate correct NOS views among junior form students who were well-motivated, and with high ability and self-confidence.

The selection for studying the SSI teaching approach as an alternative teaching approach to improving students' learning NOS was informed by the literature review. For instance, Zeidler et al. (2002) reported the SSI approach had helped to generate conflicting students' pre-existing views of NOS as controversial ideas about SSIs were presented to students. It was surprising that students performed very well in developing the NOS tenet of social and cultural embeddedness through evaluation of data with respect to the SSI. Schalk (2012) also found that the SSI-based curriculum was able to improve students' reasoning about the tenets of tentativeness and social & cultural embeddedness. Moreover, Matkins and Bell (2007) discovered that the use of global climate change issue had a positive impact on the students' perception of the tenets of subjectivity and tentativeness. Furthermore, Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum (2012) concluded that the SSI driven group was able to develop understanding of the tenets of 1) creativity & imagination, 2) tentativeness, 3) empirical based, 4) social & cultural embedded, and 5) theories & laws. Students also displayed higher ability in using SSIs to describe and explain the social & cultural embedded tenet. By contrast, Bell, Matkins and Gansneder (2011) discovered that the SSI teaching method resulted in no significant change in the learning of NOS in preservice teachers. Yet, it was the explicit teaching approach that produced a positively significant impact on those teachers in the learning of NOS. Hence, there were arguments about the effectiveness of the SSI approach in teaching NOS. However, it appeared that the majority of research reports showed that the SSI approach was useful, especially with regard to the tenet of social and cultural embeddedness. It was worthy of pointing out that there was no direct comparison between HOS and SSI in their effectiveness in promoting understanding of NOS in Hong Kong and elsewhere in the context of senior secondary Biology education.

Chapter Two also discussed the potential factors raised by scholars that had a possibility of affecting students in learning NOS. For example, Tao (2003) found that the HOS teaching approach failed to bring about the correct NOS views among well-motivated, high ability and high self-confidence junior form students. However, according to other researchers (Moss, 2001; Khan, Hussain, Ali, Majoka & Ramzan, 2011 no such relationship was observed between student achievement and the learning of NOS. Therefore, academic achievement might be a factor affecting students learning NOS under certain circumstances, for example, when certain teaching approaches were used. From other previous researches (Huang, Tsai & Chang, 2005; Tsai & Liu, 2005; Tsai, 2006) reported that male students were better than female students in learning the tenets of tentativeness, and creativity and imagination. They suggested that male students might be more able to construct integrated science knowledge, while female students might display lower interest and less confidence in the learning of science. However, there was still controversy about the gender effect on the students in learning NOS, as there were reports that no gender difference was found in secondary students, university students and science teachers in their views on NOS (Dogan & Abd-El-Khalick, 2008; Liu & Tsai, 2008). To clarify these contradictory findings, the two factors, academic achievement and gender, were also investigated in this study.

1.5.3 Chapter Three - Methodology

Chapter Three provides a detailed account of the methodology employed in this study. A mixed-method research approach was adopted to study the effectiveness of the HOS and SSI approach in teaching senior secondary biology students with a view to enhancing their understanding of NOS. A quasi-experimental design using intact groups with pre-test and post-test embedded was adopted to measure the students' performance before and after the intervention. This chapter details the sampling method. Students were drawn from four intact classes from two grades of the same school. The participants were divided into two groups - the HOS group, which used the existing HOS teaching approach, and the SSI group, which used the SSI teaching approach that is less commonly practiced in Hong Kong.

The teaching and learning materials for both intervention approaches were adopted from the textbook. They were reviewed by biology education experts before use in this study. The VNOS-D+ developed by Lederman & Khishfe (2002), a well validated instrument for measuring understanding of the seven major NOS tenets, was used both in the pre-test and post-test to compare students' understanding of NOS before and after the treatment. The VNOS-D+ takes the form of a questionnaire, with a number of open-ended questions to present scenarios for eliciting students' understanding of those NOS tenets.

All students were required to complete the questionnaire before and after the intervention to the best of their knowledge. Relevant statistical research tools including paired *t*-test, ANCOVA, and Pearson Correlations were used to compare the effectiveness of both teaching approaches based on the quantitative data obtained from the VNOS-D+. In addition, some of the students were invited to a semi-structured interview after the intervention to collect more in-depth ideas underlying the interviewees' responses to the VNOS-D+, and to triangulate with the quantitative method and data. Both the open-ended responses obtained from the VNOS-D+ questionnaire and interview transcripts were subject to qualitative analysis to identify themes under which participants of the two treatment groups might differ in their responses. The quantitative and qualitative data, when combined, could yield more objective findings for answering the research questions. After the intervention, all students received further input in the form of revision lessons specifically on NOS by going through the definition of each tenets, as well as past examination questions to consolidate their knowledge about NOS. This helps to ensure both groups received the essential input about NOS for fairness sake.

1.5.4 Chapter Four – Data Analysis and Results

Chapter Four - Data Analysis and Results - detailed the results of both quantitative and qualitative analysis through means as described in the previous chapter. Paired *t*-test, Pearson's correlation and ANCOVA were used to analyze the data quantitatively. The paired *t*-test was used to analyze the difference between the results of the pre-test and post-test for each of the two teaching approaches. Pearson's correlation was used to analyze the relationship among the seven tenets of NOS under the two teaching approaches respectively. Any correlation between the seven tenets of NOS under study and students' general biology achievement was also examined. The statistical technique of ANCOVA was used to analyze the difference among those seven tenets of NOS for each teaching approach. The same method was employed to test any effect of biology academic performance and gender on the understanding of NOS achieved by the two groups of students. To enrich the qualitative part of the data, students' open-ended responses obtained from the VNOS-D+ post-test were subject to further qualitative analysis to obtain finer and more detailed differences between the two treatment groups. This method of data analysis, to the best of my understanding, has not been employed previously by other researchers as informed by the literature review presented in Chapter Two. Likewise, the qualitative data obtained from the semi-structured interview was also subject to analysis to collect more evidences to support or reject the results gathered from the quantitative analysis.

1.5.5 Chapter Five – Discussion and Conclusion

Chapter Five - Discussion and conclusion – discusses the results of the data analysis reported in Chapter Four, leading to inferences and possible explanations about the results, and finally conclusion of the study in response to the research questions set for this study. The findings from the data analysis showed that both groups of students displayed very lower score in the pre-test. The poor pre-test result appears to echo the problem of the unsatisfactory performance of Hong Kong students in answering NOS questions in the HKDSE biology examination, by which this study was motivated. Yet, the exact reasons causing the lower pre-test score remain to be confirmed. According to the quantitative analysis, both teaching approaches, HOS and SSI, were able to improve students' understanding of NOS when used independently. However, there were some tenets of NOS displaying correlation with each other for both approaches respectively. When the effectiveness of the two approaches was compared with respect to the seven NOS tenets, no statistically significant different result was obtained. This showed that, no singular teaching approach could claim to be more effective in improving students learning of NOS than the other. When analyzing students' detailed responses obtained from the VNOS-D+ questionnaire and interview transcripts, it was discovered that certain themes emerged that were able to reflect students' thinking behind their understanding of NOS tenets. These themes include using examples to support one's claims, using historical cases as evidence to support one's claim, and extracting relevant information from more recent issues as evidence. Some of these themes were more commonly observed in one treatment group than in the other. Additionally, difference in gender and biology achievement seemed to have no significant difference in both teaching approaches according to the findings of this study. The limitations of this study were discussed at the end of this chapter.

1.5.6 Chapter Six – Implications and Recommendations

Chapter Six – Implications and recommendations – discussed the implications of the findings for three aspects. The first is the implications for biology curriculum development, with specific reference to NOS education. The second aspect is the implications for instructional practices including instructional designs and classroom pedagogy. The third aspect is the implications for assessment of students' achievement in NOS. Suggestions were raised in respect of the use of SSI and HOS in teaching NOS to senior secondary biology students. Based on the findings as well as the limitations of this study, further studies were recommended to validate the findings of this study, and to bridge any further research gaps identified.

1.6 Summary

There were no unified tenets of NOS, many scholars and researchers suggested varying tenets of NOS, and varying number of tenets that range from 4 (Lee, 2012) to 12 (Alshamrani, 2008), Nevertheless, these tenets share varying degrees of similarity. Bartos and Lederman (2014) suggested seven tenets of NOS, which were adopted for this study. This set of NOS tenets share a high degree of similarity with that stipulated in Hong Kong Science curriculum (CDC & HKEAA, 2007). It also forms the basis for devising the well-validated VNOS-D+ (Lederman & Khishfe, 2002) instrument that was adopted in this study for measuring the effectiveness of students' understanding of NOS. The study of NOS in science was not new in the field of science education, but Hong Kong was lagging behind in embedding NOS teaching in the school curriculum and public examination syllabus. The incorporation of NOS into the curriculum was only formally initiated in 2002. There were provisions by the curriculum planners of in-service teacher training for the teaching of NOS, supplemented with specially designed teaching materials for teachers' use. However, there were consistent reports from the HKEAA about poor students' performance in NOS related questions in the HKDSE over six years in a row. Against this background, the effectiveness of an alternative teaching approach – the SSI approach – was compared with that of the HOS approach, the existing approach recommended by the curriculum planners to facilitate students learning of NOS.

The study could be characterized as a quasi-experiment design, with two intact treatment groups, one receiving the existing teaching approach of using HOS, and the other group was taught through the SSI approach. Quantitative data was obtained by pre- and post-test using the VNOS-D+ instrument for assessing students' understanding of seven specific NOS tenets. Some of the participants were invited to have a semi-structured interview to solicit more detailed information about their concepts and ideas about NOS they indicated in the questionnaire. The quantitative data from the post-test and pre-test were analyzed by paired *t*-test for the HOS and SSI treatment group independently, to examine whether each teaching approach could improve students understanding of NOS after the intervention. The pre-test and post-test data of both groups were subject to further analysis using ANCOVA, with the pre-test result set as the covariate, to examine the difference, if any, between the two approaches in improving students' performance from the pre-test through to the post-test. This allows the effect of the HOS and SSI approach as reflected by the post-test score to be determined and compared after controlling for the pre-test test score. Both the paired *t*-test and ANCOVA findings will shed light on the relative effectiveness of these two teaching approaches in helping students learn the concepts of NOS.

The findings showed that there was statistically significant difference in post-test test score after each teaching approach, which meant both approaches were able to improve students in learning the concepts of NOS independently, but no statistically significant difference was observed between HOS and SSI in improving students in learning of NOS. Additionally, no interaction was found between the type of teaching approach and student biology achievement using the test of two-way ANCOVA. However, it was found that higher achievers learned the tenet of theories & laws better through the HOS teaching approach than lower achievers, but no such correlation was found in the SSI group.

Moreover, there was no statistically significant interaction between gender and the learning of NOS according to the analysis by two-way ANCOVA. The qualitative data including the detailed students' response to the post-test questionnaire and semi-structured interview revealed that more HOS students perceived scientific knowledge as governed by "knowing is seeing", which appeared to be incompatible with the NOS tenet of creativity & imagination. This finding was also supported by the data obtained from the semi-structured interview. Moreover, students taught using the SSI approach showed higher ability in using examples to explain the tenets of NOS. To conclude, both teaching approaches were able to improve students in learning the concepts of NOS, but HOS students seemed to play down the tenet of creativity & imagination and SSI students seemed to be more able to take advantage of real examples to support their claim. Further, HOS was able to help higher achievers to learn the tenet of theories & laws better than the SSI approach.

There were implications of this study for science or biology education with respect to biology curriculum development, classroom instructional practice, and the assessment of NOS. Finally, it was concluded that both the SSI and HOS approaches may be effective in improving students' learning of NOS in Hong Kong context. It was suggested that both teaching approaches may complement each other, such that educational practitioners should use both teaching approaches to deliver the concept of NOS to Hong Kong students.

2 Literature Review

2.1 Introduction

The tenets of NOS were discussed worldwide over a very long time with no unified conclusions arrived to date, and the number of tenets suggested varied from 4 to 12. Nevertheless, some degree of similarity in the tenets of NOS was shared among various scientists, researchers, educators, etc. For the purpose of this study, a reference set of NOS tenets would have to be adopted. Since the current teaching approach of NOS in Hong Kong was pre-dominantly HOS, a full inspection of the status and effectiveness of the HOS approach in teaching NOS was considered an essential part of the literature review in this chapter. Likewise, a review was also undertaken of the SSI approach as an alternative way to improve students in learning NOS. In conducting the literature review, there is also evidence from research indicating that gender and biology academic performance might contribute rather significantly to the learning of NOS.

2.2 What is the Nature of Science?

It is widely believed in literature that the nature of science (NOS) occupied an irreplaceable status in scientific literacy (Allchin, 2011; American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996). The NOS describes how scientific knowledge develops and what scientific knowledge is based on. Lederman (2007) claimed that worldwide science education institutes should treat teaching NOS as a primary focus. McComas & Nouri (2016) also claimed that the term NOS was widely used in the scope of science education and represented the most important aim of science education such that students could develop scientific knowledge in perspective. Irzik & Nola (2014) explained further that the reasons of learning NOS is to facilitate the learning of science content by (1) knowing science as a kind of human enterprise, (2) appreciating the value of science in today's world and (3) developing students' ability to make informed decisions about controversial issues so as to facilitate the development of democratic citizenship. However, the understanding of the NOS varies among researchers, scientists and international curriculum authorities, and there has yet been a consensual agreement on the definition of NOS (McComas & Olson, 1998; Abd-El-Khalick & Lederman, 2000; Ramnarain & Chanetsa, 2016).

McComas (2005, p.3) undertook a very extensive and thorough qualitative analysis of twenty-three books from 1951 to 2003. The study sought to identify different authors' ideas about NOS. The tenets of NOS as implicated by these books were ranked order based on their frequency of occurrence. As a result, a list of nine tenets of NOS were drawn up as follows:

(1) Science demands and relies on empirical evidence;

(2) Knowledge production in science shares many common factors and shared habits of mind, norms, logical thinking and methods (such as careful data recording, truthfulness in reporting, care in observation, etc.);

- *However, there is no one step-wise scientific method by which all science is done,*
- *Experiments are not the only route to knowledge,*
- *Science uses both inductive reasoning and hypothetico-deductive testing,*
- *Scientific conclusions are peer reviewed but observations and experiments are not generally repeated;*

(3) Scientific knowledge is tentative but durable. (This means that science cannot prove anything, but scientific conclusions are still valuable and long lasting because of the way in which they are developed);

(4) Laws and theories are related but distinct kinds of scientific knowledge. Hypotheses are special, but general, kinds of scientific knowledge);

(5) Science has a creative component;

(6) Science has a subjective element (Ideas and observations in science are "theory"-laden; these bias plays both potentially positive and negative roles in scientific investigation);

(7) There are historical, cultural and social influences on science;

(8) Science and technology impact each other, but they are not the same; and

(9) Science and its methods cannot answer all questions (In other words, there are limits on the kinds of questions that can be asked of science).

Subsequently, Alshamrani (2008, p.100) performed a meta-analysis based on 14 journal articles published between 1998 and 2007, twelve tenets of NOS were abstracted, which are listed as follows:

(1) Scientific knowledge is not entirely objective;

(2) Scientists use creativity;

(3) Scientific knowledge is tentative;

(4) Science is socially and culturally embedded;

(5) There is a distinction between scientific laws and theories;

(6) Scientific knowledge is empirically based;

(7) The absence of a universal step-wise scientific method;

(8) There is a distinction between observations and inferences;

(9) Science cannot answer all questions;

(10) Cooperation and collaboration in development of scientific knowledge;

(11) Science and technology; and

(12) The role of experiments in science.

Moving from worldwide to Hong Kong, the education reform in 2009 on Hong Kong Senior Secondary Education marked a new era in the teaching of the Nature of Science in Senior Secondary Science subjects. According to official documents published by Science Education Section of Education Bureau (2009, p.13), the seven tenets of NOS that were embedded in the curriculum are as follows:

(1) Scientific knowledge is tentative and subject to change;

(2) Science is socially and culturally embedded;

(3) Scientific knowledge is based on and / or derived from observations of the natural world (i.e. empirically based);

(4) Doing science requires creativity and imagination;

(5) Science is a process of ongoing inquiries;

(6) Science advances through reasonable skepticism; and

(7) Science is affected by the technology and the types of equipment available at the time.

In a research study to explore the various aspects of reasoning, such as critical reasoning, rationality of reasoning, internal psychological context and citizenship, and how they interacted in decision-making about SSIs. Lee (2012, p.461) stated that despite the difficulty for all institutes and scientists to get the agreement on the unified tenets of NOS, there were some key tenets shared by researchers. Four of them are the same as what is adopted by the CDC and HKEAA, which were (1) scientific knowledge is evidence-based; (2) scientific knowledge involved observation; (3) subjective hypotheses or theories are involved in the formation of scientific knowledge; and (4) the knowledge is subject to be changed and tentative. Elsewhere, Lederman, Antink & Bartos (2014) suggested five tenets of NOS, which were (1) scientific knowledge is tentative; (2) subjective; (3) empirically-based (based on and / or derived from observations of the natural world); (4) culturally and socially embedded; and (5) involving human inference, creativity and imagination.

At the same time, Lederman in collaboration with Bartos (Bartos & Lederman, 2014, p. 153) concluded from the NOS literature that the NOS comprises seven tenets, which are listed as follows:

(1) Scientific knowledge is empirically based;

(2) Observations and inferences are qualitatively distinct, in that the former are directly accessible to the senses while the latter is only identified through its manifestation or effects;

(3) Scientific theories and scientific laws are different types of knowledge;

(4) The generation of scientific knowledge requires, and is a partly a product of, human imagination and creativity, from generating questions to inventing explanations;

(5) Scientific knowledge is theory-laden (i.e., influenced by scientists' prior knowledge, beliefs, training, expectations, etc.);

(6) Scientific knowledge both affects and is affected by the society and culture in which it is embedded; and

(7) Scientific knowledge, while reliable and durable, changes.

Table 1 Comparison of different NOS tenets proposed by various authors

Tenets of NOS	McComas (2005)	Alshamrani (2008)	Lee (2012)	Lederman et al., (2014)	Bartos & Lederman (2014)
Empirical-based	✓	✓	✓	✓	✓
Observation & inference		✓	✓	✓	✓
Theory & Law	✓	✓	✓		✓
Creativity & imagination	✓	✓		✓	✓
Tentativeness	✓	✓	✓	✓	
Subjectivity	✓	✓	✓	✓	✓
Social & cultural embedded	✓	✓		✓	✓
Interaction between science and technology	✓	✓			
Science unable to answer all questions	✓	✓			
Cooperation and collaboration in science knowledge production	✓	✓			
No common stepwise scientific method		✓			
Doing experiment is important in science		✓			

✓ means the idea present in that article

Table 1 showed that NOS tenets adopted by the various authors under review. It was worth noting that the set of NOS tenets adopted by Bartos and Lederman (2014) was mostly adopted by other authors as well. Hence, there is greatest similarity between Bartos and Lederman's and those proposed by other researchers. This is taken to imply that their set of NOS tenets is widely accepted by the NOS research community. In this study, the seven tenets defined by Bartos & Lederman (2014) were adopted in this study to guide the development of the theoretical framework, design the methodology, and evaluation of the effectiveness of the two approaches in promoting students' understanding of NOS, as well as possible influences of gender and biology academic achievement. The decision to adopt this set of tenets are justified as follows:

First, Bartos & Lederman's set of NOS tenets are sufficiently generic and could encompass most of the views of NOS proposed by other researchers, as explained in the previous paragraphs and Table 1.

Second, their tenets are similar to those promulgated by CDC and HKEAA (2007). This argument is supported by a detailed comparison of the different tenets of NOS between the Hong Kong Science Curriculum (CDC and HKEAA, 2007) and Bartos & Lederman (2014). Table 2 shows the results of the comparison. In the table, those tenets that are closely related with each other are grouped under the same item in the first column from the left. For instance, for item A, tenets 1 and 7 from the HK curriculum were grouped together as they both relate scientific knowledge as tentative, due to technological limitation at present, which is subject to change with technology advancement in the future. The ideas were similar to item 5 of the Bartos & Lederman's study. For item B, the tenets in both documents suggest the idea that the generation of scientific knowledge is affected by social and cultural factors. Item C describes the scientific knowledge was a result of the experience in the past. For item D, both documents mentioned that scientific knowledge development involves creativity and imagination.

Lastly, for item E, the Hong Kong science curriculum described two ideas (tenets 5 and 6) – science is a process of on-going inquiries, and science advances through reasonable skepticism. Both ideas could be linked with each other, and collectively imply that science knowledge is not entirely objective but subjective. Yet, this subjective knowledge would become less subjective through providing evidence support and exercising reasonable skepticism in the process of ongoing inquiries. Hence, these two ideas about NOS is considered to a certain extent comparable with tenet 6 – scientific knowledge is subjective, which is affected by the human's prior knowledge in science – as described by Bartos and Lederman (2014). However as far as the item of subjectivity is concerned, Bartos and Lederman's tenet is in better alignment with the views of other researchers in the literature (e.g., McComas, 2005).

As the seven tenets described by Bartos and Lederman (2014) are largely comparable with those laid down in the science curriculum of Hong Kong, they could provide a suitable reference for studying Hong Kong students' understanding of NOS. Their similarities imply that the findings of this study could be readily related and applied to the curricular and learning contexts of Hong Kong schools.

The third reason for adopting Bartos and Lederman's tenets is that a related instrument is readily available for assessing students' understanding of these tenets. The instrument is the VNOS-D+ questionnaire, developed by Lederman & Khishfe (2002), which is in alignment with this set of tenets. Since this questionnaire is well validated and has been used by many researchers in their research studies on NOS, it could be readily applied to this study in answering the research questions. Details of the VNOS-D+ questionnaire and the way in which it was administered were discussed in the next chapter – Methodology.

Table 2 Comparison of NOS tenets adopted by the Hong Kong Science Curriculum and Bartos & Lederman (2014)

Item	NOS tenet in Hong Kong Science Curriculum	NOS tenets suggested by Bartos & Lederman (2014)
A	(1) Scientific knowledge is tentative and subject to change; (7) Science is affected by the technology and the types of equipment available at the time.	(5) Scientific knowledge is tentative, which the knowledge is subjected to change when the new evidence discovered by an advanced technology or new theory to interpret the existing knowledge;
B	(2) Science is socially and culturally embedded;	(7) Scientific knowledge is interactive with both society and culture;
C	(3) Scientific knowledge is based on and / or derived from observations of the natural world (i.e. empirically based);	(1) Doing science is based on experience, it is also based on and derived from experiments; (2) Scientific knowledge is based on observation and inference, there is qualitatively distinction between them;
D	(4) Doing science requires creativity and imagination;	(4) Creativity and imagination are involved in the production of scientific knowledge;
E	(5) Science is a process of ongoing inquiries; (6) Science advances through reasonable skepticism;	(6) Scientific knowledge is subjective, which is affected by the human's prior knowledge in science;

Note: Tenet (3) of Bartos and Lederman's version could not be matched with any tenet of the HK Science Curriculum.

(3) theories and laws are the scientific knowledge, but they are different in meaning, scientific laws are reports or explanations of the relationships among observation; scientific theories are inferred explanations for observation.

2.3 HOS and NOS

There were many research papers studying the effect of the HOS approach on the improvement of NOS learning. Some papers indicated the HOS approach could successfully improve the learning of NOS (Abd-El-Khalick & Lederman, 2000; Yip, 2006; Wolfensberger & Canella, 2015). However, there are others showing that there was no change or improvement after the intervention (e.g., Tao, 2003). Hence, the results of using HOS in improving the learning in NOS are rather inconclusive. The details of the literature review in this respect are discussed in the paragraphs that follow.

Abd-El-Khalick and Lederman (2000) developed a study to test the effect of HOS courses on the conception of NOS among post-secondary students and pre-service teachers. The study examined the effectiveness of HOS courses on the ability of participants to elaborate on their understanding of NOS tenets. It went on to explore what factors of the course could influence students learning of NOS. There were 181 participants, of which the number of graduate and undergraduate students, and pre-service secondary science teachers were 166 and 15 respectively. All subjects completed an open-ended questionnaire, followed by individual interviews, so as to evaluate subjects' understanding of NOS before and after the intervention. They found that the majority of subjects improved a little in their views of NOS after completion of the course, and that their pre-learning knowledge about NOS was insufficient before entering the HOS course. The authors reported that it was the difficulty inherent to the course that impeded students learning NOS. They suggested that the historical episodes might be insufficient for students to experience the conceptual shift from the history of science to the learning of science. However, it was found that the pre-service teachers learned NOS better than other students through the same HOS approach. The reason might be related to the fact that those pre-service teachers studied science education as their major, or that specific NOS tenets were specifically focused upon during the HOS course, which facilitated students' learning.

Yip (2006) also did the study like Abd-El-Khalick and Lederman (2000), using science teachers as the subject to study the use of history in science in fostering science teachers' understanding of the nature of science. All teachers were university graduates specializing in different science areas. They went through an initial teacher training course, and did pre-test and post-test before and after the intervention to evaluate their understanding of the NOS. During the intervention, all subjects received two episodes about the historical development of ideas about science. The first one was a video, which recorded a debate about the shape of the Earth, and the second one was a power-point presentation about the cause of gastric ulcer. They then identified the steps of scientific inquiry with the aid of some guided questions. The author found that many teachers had incorrect views about the nature of science and failed to have good understanding of the process of generating scientific knowledge before the intervention. However, the findings indicated the subjects displayed an enhanced perception of the nature of science after the intervention. Therefore, he concluded that using historical method to demonstrate the nature of science was effective. In summary, there are three advantages of using the HOS approach in teaching NOS. First, concrete examples could be provided by historical stories to show how science actually worked; Second, the thinking of early scientists was in great contrast to the unconscious or common-sense reasoning commonly practiced by students; Third, those episodes depicting the evolution and revolution of scientific knowledge posed great mental challenges to the subjects.

Despite these, the HOS approach seemed only effective in improving the learning of NOS for pre-service teachers, who have science background. How about secondary students, which lack such background? Wolfensberger and Canella (2015) conducted research to investigate how cooperative learning could assist the learning of NOS through the HOS approach. Two experienced biology teachers conducted the investigation with four lessons designed to teach NOS. The scientific discovery of Archaeopteryx, an extinct reptile-like and bird-like organism, was used as the context for the inquiry, focusing on the early research of Archaeopteryx. The participants were 68 10^{th} and 11^{th} grade senior secondary students drawn from five classes of a Switzerland high school. The research adopted a qualitative approach, with data collected through video-recorded group work, questionnaires, pre- and post-tests using VNOS-C to assess students' NOS ideas. Semi-structured interviews were also conducted with the students and teachers. The researchers discovered that students showed more informed interpretations of such NOS tenets as theory-laden scientific observation, social & cultural embeddedness and tentativeness. This showed that the HOS approach might only improve some tenets of NOS in secondary students but not the others. This finding might be related to the specific context of the case brought up for discussion. In this study, the research on the fossil of Archaeopteryx was used to bring out the NOS concept by presenting different scientists' explanations to account for the fossil, which may be more conducive to learning those NOS tenets. There were other limitations to the study as well, which include small sample size, the data sources for examining the students' conceptions limited only to written questionnaire and lesson observation, and the interview scripts not being used for data analysis, but just for providing a richer qualitative picture. As a matter of fact, the authors themselves cast doubt about whether a single HOS case was able to improve all tenets of NOS. This implies the need to include more than one case in HOS courses, so as to cover more tenets of NOS.

Tao (2003) studied the change in junior form students' understanding of NOS after going through the HOS approach. The author used science stories as the stem of the lesson and developed NOS in students by peer collaborative learning. The tenets of NOS were

> *1) scientific discoveries are for understanding nature; inventions are for solving problem and changing people's way of life;*
>
> *2) science and its methods cannot give answers to all questions;*
>
> *3) scientists usually work in collaboration and one scientist's work is often followed up by other scientists;*
>
> *4) scientists carry out experiments to test their ideas, hypothesis and theories;*
>
> *5) careful and systematic study is not enough; scientists need to be creative and imaginative;*
>
> *6) scientific theories are created by scientists to explain and predict phenomena; they do not necessarily represent reality; and*
>
> *7) scientific knowledge, while durable, has a tentative character* (Tao, 2003, p. 149).

The science stories were adopted from the United Kingdom (Solomon, Duveen & Scott, 1991), which were used for teaching NOS in the national science curriculum. The subjects were 150 Secondary One students from a secondary boy's school in Hong Kong. The intervention spanned 5 lessons, lasting about 200 minutes in total, with pre-test and post-test. The test consisted of four multiple-choice questions, which focused on the tenet of empirical evidence and that of theory & law. Some students were chosen to participate in an interview designed to probe more deeply into their understanding of NOS. The author found that students held inadequate views on NOS drawn from their prior knowledge and they tended to regard scientific theories as absolute truth. As a result, they selectively chose certain tenets of the stories to support their inadequate interpretations. In the peer collaboration setting, students' arguments for inadequate views sounded reasonable and changed other students from one inadequate view to another inadequate view, rather than towards the adequate one. Therefore, this seemed to prove that the HOS approach failed to bring about correct NOS view in students. There were several possible reasons for such failure. Although the subjects were all well-motivated with high ability and high self-confidence, the setting mainly involved peer collaboration without teacher scaffolding after the discussion, thus resulting in students diverging very far away from focused learning. Moreover, the instrument could not cover all the major tenets of NOS, but only the tenets about 'empirical basis' and 'theory and law'. This leads one to question about the effectiveness of the HOS as an approach for teaching NOS. There are queries about whether the approach is effective for those students that have low ability and self-confidence, as well as those who are less well motivated? There are also questions about possible differences in the effectiveness of this approach across gender as only male students were involved as subjects in the study.

2.4 SSI and NOS

There were increasing researches studying the improvement of NOS learning by using the SSI approach. Some of these indicated the SSI approach could successfully improve the learning of NOS (Eastwood et al., 2012; Matkins and Bell, 2007; Schalk, 2012; Zeidler, Walker, Ackett & Simmons, 2002). However, other researches showed that there was no change or no improvement after the intervention (Bell et al., 2011; Walker & Zeidler, 2007). The results so far were inconclusive. Relevant literatures were discussed in subsequent paragraphs.

Zeidler et al. (2002) investigated the relationship between students' understanding of NOS and their responses to socio-scientific issues that presented evidence contradictory to students' beliefs. This study was divided into three stages. At stages one and two, there were 248 students belonging to grades 9^{th} & 10^{th}, grades 11^{th} & 12^{th}, and pre-service science teachers from the college. At stage one, students were requested to respond to an open-ended questionnaire focusing on the following tenets of NOS,

1) tentativeness;
2) empirical evidence;
3) social & cultural embedded; and
4) creativity & imagination.

At stage two, students were requested to respond to another open-ended questionnaire focusing on an SSI with ethical implications for research on animals that call for moral reasoning. Stage three involved a qualitative research, targeted at 82 students selected from the participants of the questionnaire. The selection of participants was based on their responses at both stage one and two. These 82 students were divided into 41 pairs. Each pair was provided with critical responses to the issue with different levels of variation. They were then interviewed by the authors according to a semi-structured protocol. In the interview, they were further challenged as to their core beliefs by providing with two sets of "authoritative readings" that might be contradictory to their views. The authors reported that students displayed conflicting pre-existing views on NOS and reasoning on the issue when controversial ideas were presented to them. Surprisingly, students performed very well with respect to the cultural and social tenet in NOS. However, variation was observed in the participants' perceptive processes from high school students to college students. The authors attributed the reason to the students' differences in science learning experiences.

Schalk (2012) used an SSI-based curriculum to teach microbiology course to undergraduates. A total of 26 undergraduates participated in the study that lasted 15 weeks, during which qualitative data was collected in two ways. First, pre- and post-data on the students' NOS conceptualization was collected by a questionnaire. Second, data was collected after two 75-minute lectures and two 60-minute laboratory sessions in the form of journals, research projects, laboratory reports, laboratory tests and evaluation. The data was analyzed with member-checking instrumental triangulation, with the computation of inter-rater reliability. The author found that the intervention was able to improve the students' reasoning skills and understanding of the NOS tenet - 'Scientific is uncertain and subject to change'. According to the data from the lab quiz and survey on the participants, the participants reported that they developed epistemological conceptualizations when they used their experiential knowledge obtained from the intervention, such as laboratory tests and research projects. Also, the participants reported that they discovered the experimental result and data could not produce definitive conclusions, which prompted them to evaluate the scientific knowledge. They also used this understanding to examine the interaction between science and society. Finally, they found the tentativeness of scientific knowledge as one of the tenets in the nature of science. The author concluded that students' learning of microbiology through the SSI-based curriculum could at the same time enhance their understanding of NOS.

Matkins and Bell (2007) used the topic of weather change as an SSI to facilitate the learning of NOS by 15 university students, majoring in elementary science teaching course. The first nine hours of the intervention focused on the global warming issue and the nature of science linked to seven tenets, which were displayed as follow,

1) empirical nature of scientific knowledge;

2) tentative nature of scientific knowledge;

3) role of creativity in scientific knowledge;

4) subjective nature of scientific knowledge;

5) roles of observation and inference;

6) theories versus laws; and

7) social and cultural influences.

After this, another 9 hours of the intervention provided explicit examples of NOS. All participants were asked to fill in a VNOS-based open-ended questionnaire with nine questions about their views on NOS before and after the intervention. The questionnaire also contained some questions about global warming change. Six of the respondents were interviewed to validate their responses to the questionnaire. The result indicated that the use of global climate change issue had a significant positive impact on the students' perception of the NOS, such as theory & law, subjectivity and social & cultural influences. Subsequent to the NOS instruction in the context of the SSI, the respondents were able to point out how scientists discriminated scientific theories and scientific laws. The issue also conveyed to students the idea of subjectivity in scientific research by displaying disagreements among scientists over the interpretation of data; and explored the impact of society on scientific knowledge development. However, it was only proved to be useful to students at the university level. It is uncertain whether similar effects could be obtained when the same intervention is applied to secondary students.

Eastwood et al. (2012) conducted an investigation to study the effect of different teaching approaches on students' NOS conceptions. Two approaches were employed, one of which was driven by socio-scientific issues while the other was driven by subject content. Two classes were randomly assigned to use SSI-driven approach, and another two classes randomly selected to use the content-driven approach. Participants were drawn from four 11th and 12th grade science classes in Florida. Both groups received explicit-reflective NOS instructions and different teaching approaches for a year. For data collection, both groups completed the VNOS form C with open-ended questions before and after the intervention. Researchers then collected the data and developed a valid coding scheme for rating. Finally, they categorized the students' NOS ideas into 6 tenets; *creativity and imagination, tentativeness, empirical-based, social and cultural influences, distinctions between laws and theories,* and *the use of scientific models*. Both groups recorded statistically significant improvement for most of the NOS tenets. However, the finding showed that the SSI-driven group was able to use more examples to describe and explain the social and cultural tenet of NOS.

In another research study about the influence of the SSI approach on students' development of NOS, Bell et al. (2011) examined the differential effect of explicit and implicit teaching of NOS with and without the use of SSI. The tenets of NOS that were focused upon were empirically based, tentativeness, subjectivity and human interference. The issue they employed was global climate change and global warming. 75 pre-service teachers were divided into four groups to participate in the intervention. These four groups were: implicit NOS with SSI; implicit NOS without SSI; explicit NOS with SSI and explicit NOS without SSI. Data was collected through pre- and post-questionnaires based on VNOS-B with nine open-ended questions, semi-structured interviews, and student journals. These data was subject to both quantitative and qualitative data analysis. It was found that teaching with SSI or without SSI yielded no significant change on the learning of NOS, but teaching NOS explicitly rather than implicitly produced significantly positive changes to the learning of NOS.

Walker & Zeidler (2007) conducted a study by using an SSI about genetically modified foods to promote debate and student discourse on the different tenets of NOS, such as tentativeness, creativity & imagination, subjectivity, and social & cultural influences. 36 senior high school students were drawn from two science classes of the same school. The study spanned seven consecutive lessons, each lasting 90 minutes. The students first participated in specially designed web-based teaching activities to study the contemporary issue of genetically modified foods. They then discussed questions intended to stimulate their thoughts about NOS in relation to certainty, tentativeness, validity, reliability, objectivity, subjectivity and social and ethical issues. After that, they were engaged in a debate, with different roles and positions assigned to them to spark arguments. The researchers gathered data from observation, students' artifacts, classroom debate video, and student interview transcripts after the intervention. The authors discovered that there were no tenets of NOS displayed during the debate in the classroom, but students could make use of evidence to prove and explain the content of NOS in the questionnaire after intervention. Thus, the authors suggested that SSI could be incorporated into the activity design to lead students to explore the various tenets of NOS, with a view to improving their concepts of NOS.

In summary, the literature reviewed in this section reveals some persistent disagreement over the effectiveness of the HOS approach in facilitating the learning of NOS. By contrast, the review shows the potential of the SSI approach, despite some inconsistencies in the findings, to emerge as an effective alternative approach to facilitate students' development of understanding of NOS. However, there was no empirical study to date in the field of science education that compared the influences of the HOS and SSI approaches on the learning of NOS tenets in secondary biology students. In light of this research gap, the present study intended to investigate the effectiveness of using HOS to teach NOS in biology, a science subject, in comparison with the use of SSI, with subjects drawing from the same school. This was achieved by the use of a well-validated instrument – the VNOS D+ - for assessing students' understanding of NOS. The VNOS D+ is a questionnaire with open-ended questions for measuring students' understanding of seven tenets of NOS, namely *tentative, empirical, inferential, imaginative and creative, cultural and social embedded, laws and theory, subject to change* and *theory laden*. These seven tenets were widely accepted by the NOS education community based on the above literature review. To enhance the validity of the study, a quasi-experimental design was employed with two different treatment groups drawing from the same school, one of which received the HOS approach, and the other received the SSI approach. In view of the relative merit of explicit intervention over implicit intervention for implementing NOS education, the two approaches were specially designed to teach NOS in an explicit manner. The intervention period spanned about one week. It was expected that this comparative empirical study could help to find out the factors that may facilitate students in learning NOS tenets. This study aimed to seek a better way to address the persistent problem of students' poor performance in HKDSE on NOS aspects in the medium term, as well as improving senior secondary biology student learning of the different tenets of NOS in the long term.

2.5 NOS and Gender

Tsai (2006) conducted a survey to investigate Taiwanese high school students in response to the understanding of the nature of science among male and female students with a view to exploring possible gender difference. A survey was administered to 428 high school students based on a five-point Likert scale questionnaire. It was found that male students tended to agree to a greater extent than female students regarding the NOS tenets of *tentativeness* and *creativity*. The authors postulated that the difference might be due to male students being more able to use more meaningful ways to learn science, hence they were able to construct more integrated science knowledge. However, due to the limitation of the research design that focused only on those two tenets, gender differences in the learning of the other NOS tenets remains to be examined before any firm conclusion could be drawn.

Tsai & Liu (2005) designed a study to develop a multi-dimensional instrument for assessing 630 Taiwanese high school students' views toward science. The dimensions measured overlapped with the tenets of NOS, these dimensions were social factor, creativity, theory-laden, cultural factor and tentativeness. The result of their study revealed that female students seemed to be less able to develop the NOS tenets of creativity and tentativeness than male students. The authors suggested that female students might be weaker than male students in perceiving the tenets of creativity and tentativeness in NOS. They attributed this finding to the possibility that female students might show lower interest and less confidence in learning science in general, which fits with the general pattern of gender difference as informed by science education literature.

Huang, Tsai and Chang (2005) developed a scale to measure the learning of the nature of science among young adolescents. The scale purported to meaure student learning of the nature of science with respect to the subscales of *the invented and changing, the role of social negotiation* and *the cultural tenets*. The researchers invited more than 6,000 senior primary students from the northern part of Taiwan to participate in the study. The study revealed that there were statistically significant differences betweeen the two genders on their performance in the subscales of *invented and changing tenet* and *the role of social negotiation tenet*. Male students tended to show better gains in those tenets from their learning of the nature of science than female students.

By contrast, Dogan and Abd-El-Khalick (2008) obtained different results in the survey they conducted in Turkey for Grade 10 students and science teachers to assess their conceptions of the nature of science. A total of 2,020 students and 362 teachers participated the survey. The finding showed that there was no relationship between gender and their views of nature of science for both teachers and students.

Liu and Tsai (2008) conducted a study to examine whether there were differences in science major and non-science major undergraduates in their scientific epistemological views. The views explored in this study included five NOS tenets: "social", "invented and creative", "theory-laden", "cultural", as well as "changing and tentative". A total of 220 undergraduates from two universities participated in the study. Consistent with the findings obtained by Dogan and Abd-El-Khalick (2008), Liu and Tsai (2008) reported that there was no gender difference on any of the tenets of epistemological beliefs among college students.

From the literature reviewed in this section, there was still a lack of consensus about possible gender effects on students' learning of NOS. Such disagreement is not only related to whether there is gender difference in students' views of NOS, but also related to the receptiveness across gender in the learning of NOS, and whether there is any gender variation in their views and learning of individual NOS tenets. There has also been a lack of consensus of the reasons underlying such differences, even though gender differences could be established. For instance, whether males have inborn benefits in the learning of science, or that they are equipped with a better ability to construct science knowledge from different evidence, or that females have less confidence in learning science.

2.6 NOS and academic performance

Another factor worthy of researching that may have implications for NOS learning is student academic performance. Moss (2001) conducted a research study to examine US senior form Biology students' learning of NOS through implicit project learning over an academic year. The study adopted a qualitative research method, with five students drawing respectively from grade 11 and grade 12 of the same school as participants. The participants were divided into three groups according to their levels of academic achievement, with two from the higher achievement level, two from the middle level, and one from the lower level. The grouping was based on the students' achievement history in science subjects. The participants were invited to participate in a semi-structured interview for six times during the year, with each interview lasting 45 minutes. The interview data was subject to content analysis. His findings showed that there were no distinctive patterns or variations observed that were associated with the student achievement. However, there were limitations to the research due to the small sample size, which casted doubts upon the reliability of the findings.

Khan, Hussain, Ali, Majoka & Ramzan (2011) performed a study to investigate the effect of inquiry-based teaching on different academic achievers in science subject. The subjects were 70 students drawing from grade 10 of a single school in Pakistan. The participants were evenly divided into an experimental group and a control group based on their pre-test test scores, which were the achievement scores for the previous test in chemistry. Each group had 35 students. Both groups were taught using the same traditional teaching method in chemistry. However, for the experimental group inquiry-based teaching was employed as an additional teaching strategy. The achievement scores of the students after the intervention were collected as the post-test result. The result was that the higher achievers in the experiment group performed better than those in the control group. It could be inferred that inquiry-based instruction seemed to have enhanced the learning of higher achievers. By contrast, for the lower achievers, there was no statistically significant difference between the experimental group and control group. Hence, the findings led to the conclusion that inquiry-based teaching was useful only for higher achievers. This study yielded rather convincing results in support of the existence of differences across the academic ability range in students' receptiveness of inquiry-based teaching. However, this finding might not be applied to the learning of NOS, as NOS is related to scientific inquiry to a certain extent. In sum, there exists a big research gap in NOS education literature regarding the influence of student academic ability in mediating the learning of NOS, let alone their impact on the effectiveness of different approaches in teaching NOS. This implies that there are plenty of rooms for further studies in this area.

2.7 Theoretical Framework

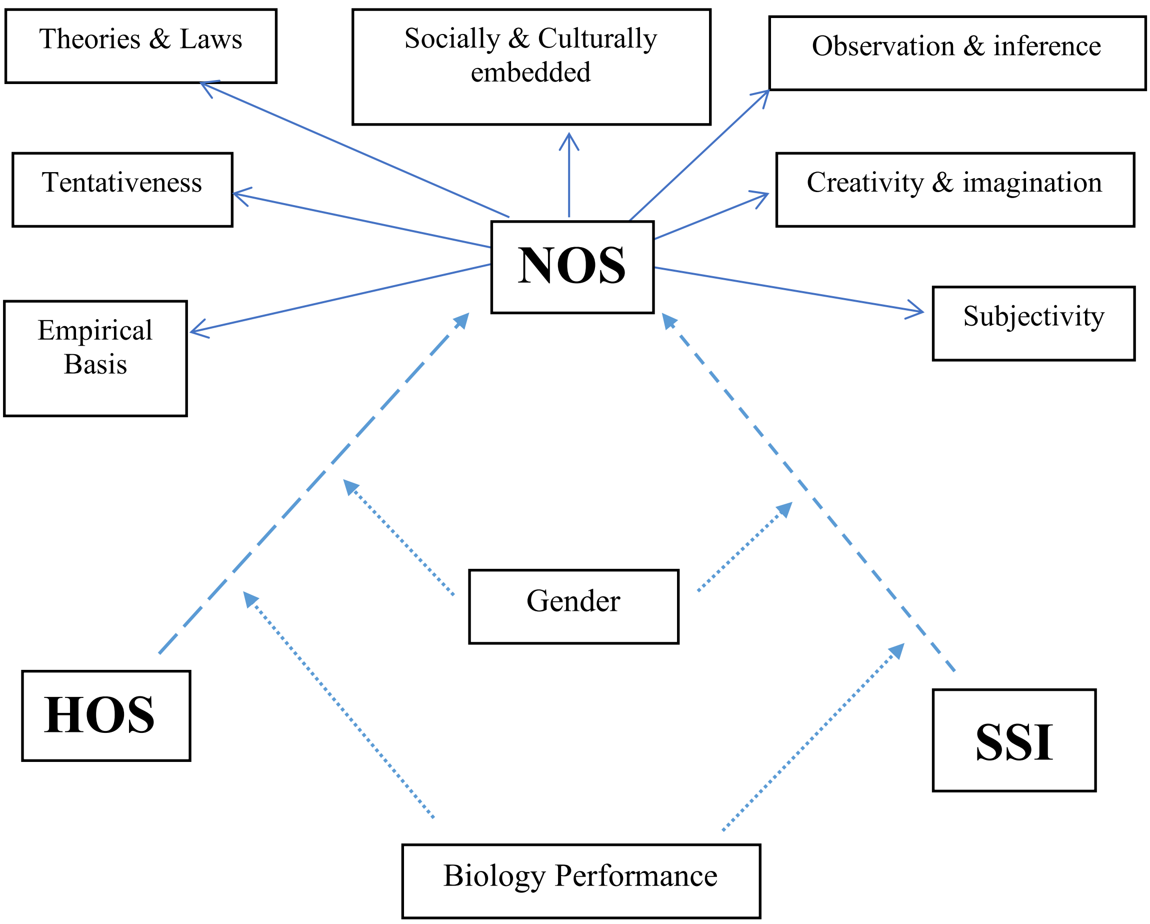


Figure 1 Theoretical Framework of this research

*

Dashed lines represent possible influences on NOS.

Dotted lines represent possible mediating effects.

Solid lines represent NOS as comprising different tenets, and each tenet is liable to be influenced by the HOS or SSI approaches either individually or collectively.

The theoretical framework of this research study was informed by the literature with regard to the two approaches to deliver the concepts of NOS to students: the HOS and SSI approaches. The HOS approach is the approach currently recommended for use in the official science curriculum issued by the Hong Kong Education Bureau since the curriculum revision in 2002. In this approach, stories describing how the scientists made their discoveries and inventions were used as a means to develop students' understanding of the nature of science, including tentativeness, subjectivity, creativity, social-embeddedness and evidence-based. There were many researches indicating that using HOS as the means to deliver NOS to students had resulted in improvement in students' understanding of NOS (Abd-El-Khalick & Lederman, 2000; Allchin, 2012; Bybee et al., 1991; Hottecke et al., 2012; Lin & Chen, 2002; Solomon et al., 1992; Rudge & Howe, 2009; Rudge et al., 2014; Wahbeh & Abd-El-Khalistan, 2014; Yip, 2006).

However, there were doubts about the appropriateness of the HOS approach, which was the officially endorsed approach in Hong Kong. The Annual Reports of Hong Kong Examination Authority on the Diploma of Secondary Education Examination consistently reported on the poor performance of Secondary Six students in the area of NOS. As an educational practitioner, it was important to improve students' performance in this part relative to the other parts by seeking more evidence about the effectiveness of the present approach and alternative approaches.

On the other hand, findings from recent researches appear to suggest that the SSI approach was capable of improving student learning of the concepts of NOS (Eastwood et al., 2012; Matkins and Bell, 2007; Schalk, 2012; Walker & Zeidler, 2007; Zeidler et al., 2002). However, in previous research studies, there has not been a direct comparison of the effectiveness of these two teaching approaches within the same school context in delivering the concepts of NOS to Senior Secondary Biology students.

In the theoretical framework formulated in Figure 1, it was hypothesized that using SSI as an alternative teaching approach may be able to improve senior secondary biology students in learning the concepts of NOS on a par with the existing approach of HOS. These two approaches, however, may exert different impacts on the learning of individual NOS tenets. It was also postulated that gender may exert a mediating effect on the learning of NOS whichever approach is used, in the light of previous findings that male students were better than female students in learning of the concepts of NOS (Huang et al., 2005; Lin, Goh, Chai & Tsai, 2013; Tsai & Liu, 2005; Tsai, 2006). Although there have been few researches conducted to examine the influence of general biology academic performance on students learning of the concepts of NOS, there have been findings that suggest positive correlations between academic ability and other aspects of science learning such as inquiry-based learning. Hence, general biology academic performance was also included in the theoretical framework as a potential mediator influencing the effectiveness of the curricular approach on learning NOS.

2.8 Summary

According to the findings from the literature review presented in this chapter, there were different views or findings on whether the HOS approach could improve students learning of NOS, and to what extent the approach is effective. Some researchers claimed that HOS was effectiveness in improving student learning of NOS, while other researchers reported that the SSI approach appeared to achieve the same effect. To make interpretation of these findings even more complicated, the NOS tenets targeted for study also varied quite a lot, which makes it difficult to draw any straightforward conclusion by directly comparing the results of different researches. A very important finding from the literature review was that there were no research studies directly comparing the HOS and SSI teaching approaches in improving students learning of NOS in similar learning context, thus leaving a research gap to be filled. This thesis is aimed to bridge this research gap by comparing the two alternative teaching approaches, HOS and SSI, for improving students learning of NOS. Nonetheless, the findings from the literature review provided a framework to facilitate the framing of this study for comparing the effectiveness of these two teaching approaches for senior forms of biology students to learn the concept of NOS. Not only were the teaching approaches examined, this study also aimed to find out whether gender and student general performance in biology would affect student learning of NOS.

Based on the literature review presented in this chapter, the theoretical framework (Figure 1) describe the relationship between the student learning outcomes in terms of their understanding of the seven tenets of NOS, and the two major teaching approaches. It also depicts how the relationship between the two are possibly mediated by gender and biology academic performance.

Based on this theoretical framework, the research questions for this study were stated as follows:

(1) Could the SSI and HOS teaching approaches enhance Hong Kong senior secondary students' understanding of the major tenets of NOS?

(2) Which approach, the SSI approach or HOS approach, is more effective in helping Senior Secondary Biology students develop more informed conceptions of the major NOS tenets?

(3) Are there any influences of gender or biology performance on the students' learning of NOS using either of two approaches?

3 Methodology

3.1 Introduction

This was a small-scale study of the effect of two different teaching approaches, the HOS and SSI, on promoting the teaching of NOS tenets to senior secondary biology students of a Hong Kong secondary school. Two teaching activities were specially designed for this study, each of which was based upon one of the two teaching approaches. The engagement time for the two activities was identical to ensure fairness. A mixed-method approach was adopted for this study. This approach allowed the collection of both quantitative and qualitative data to enrich the database as well as for triangulation of research methods to improve validity and reliability of the findings. The main research procedure and instrument was based on VNOS procedures (Khishfe & Abd-El-Khalick, 2002), which were well validated and employed by NOS researchers (Abd-El-Khalick, 2011; Bell et al., 2011; Chen, 2006; Erdas Kartal, Dogan, Irez, Cakmakci & Yalaki, 2019; Erumit, Fouad & Akerson, 2019; Fouad, 2015; Khishfe & Lederman, 2006; Lederman, 2002; Pavez, Vergara, Santibañez & Cofré, 2016; Özer, Doğan, Yalaki, Irez & Çakmakci, 2019; Sadler, Chambers & Zeidler, 2004). This instrument and procedure were adopted to evaluate students' views on NOS collected from the two treatment groups before and after learning through either the HOS or SSI approach. The VNOS instrument is a questionnaire with open-ended questions designed to elicit and assess students' understanding of NOS based on their responses to each of the questions. It has three different versions developed at different times - form A (Lederman & O'Malley, 1990), B (Abd-El-Khalick, Bell & Lederman, 1998) and C (Griffard, Mosleh & Kubba, 2013; Mulvey, Chiu, Ghosh & Bell, 2016). These different versions had been administrated to about 2000 respondents, who were pre-service and in-service primary and secondary science teachers, undergraduates and graduates, and secondary school students.

The qualitative part of the data consisted of the detailed responses provided by the students in the VNOS-D+ questionnaire, together with the data obtained from a semi-structured interview. This part of the data is intended to collect deeper ideas of the participants, and to identify further evidence of their understanding of the seven NOS tenets obtained from the VNOS questionnaire, Therefore, this mixed methods approach that combined the use of VNOS with an interview protocol could hopefully enhance the validity in assessing the understanding of NOS among secondary students at a high confident level (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002).

3.2 Sampling

The study adopted a quasi-experimental design. A total of 67 Secondary students were enrolled in four intact classes, two of which were from Grade 11 and two from Grade 12 in Hong Kong. In each grade, one class was using English (EMI) as the teaching medium while the other class was using Chinese (CMI). Hence there were one CMI and one EMI class in Grade 11 and one CMI and one EMI class in Grade 12. The age of the participants ranged from 15 to 18, with an average of 16.5 when all classes were taken together. The two approaches were randomly assigned to the two intact classes at each grade level by flip of a coin. As a result, students in the EMI class of Grade 12 and the CMI class of Grade 11 were assigned into the SSI group who was taught using the SSI approach. In this group, there were 33 students, 13 males and 20 females. Their mean age was 16.4 years old and the age range was from 15 to 18. Students in the CMI class of Grade 12 and the EMI class of Grade 11 were assigned to the HOS group, which used HOS as the teaching approach. In this group, there were 34 students, 16 males and 18 females. Their mean age was 16.7 years old and the range was from 15 to 18. Thus, each group consists of one EMI and one CMI class respectively (Figure 2). As intact classes were used for the assignment of treatment methods, the two groups, HOS and SSI, were regarded as non-equivalent comparison groups. This design was the one of the most widely used experimental designs in educational research in view of the typical class structure within a school. Hence, this study design did not have the benefits of random assignment of participants to either of the two treatment groups. However, the assignment of the four intact classes to the two treatment methods was by random, which is in alignment with the suggestion by researchers (e.g., Campbell & Stanley, 1963).

Figure 2 The figure displaying the distribution of students subjecting to the two teaching approaches

HOS group	**SSI group**
Grade 12 CMI	Grade 12 EMI
Grade 11 EMI	Grade 11 CMI
34 students (16 Males & 18 Females)	33 students (13 Males & 20 Females)

3.3 Ethical consideration

67 students participated in this study from the same school with Grades 11 and 12 on the effectiveness of HOS and SSI in learning of NOS, their parents signed consent forms, and all agreed to join the study. The school consent was also obtained from the Principal. As all participants were Chinese participants, the teaching medium used throughout the study was

Chinese (Cantonese), as so to maintain consistency and fairness across the two groups, and remove any undue influences arising from the language barrier or language benefit. In order to achieve both the aim of the research and that of students' learning, English translation for special technical terms were provided, for example, the seven tenets of the nature of science. This was to align the medium of instruction used in this study with the regular lesson to ensure the students could communicate important concepts in English. Moreover, all students received the same instruction when it came to the final revision on NOS to prepare them for their school and public examinations. This would ensure any possible differences in the learning of NOS are due to difference in intervention, while at the same time safeguarding students against any deficiency in learning NOS as a result of the different intervention students would receive. The final revision after the intervention covered the definitions of all tenets of NOS with description and elaboration. Students would also have ample opportunities to practice answering past examination questions regarding NOS.

3.4 Instruments

After a systematic review on the tenets of NOS from various researchers as detailed in Chapter two, Bartos & Lederman's (2014) categorization of NOS tenets was adopted. Their categorization of NOS tenets is sufficiently generic, covering the essential views of NOS identified from the literature. Those tenets are also similar to the tenets promulgated by CDC and HKEAA (2007), hence they are considered to match reasonably well with the Hong Kong context. To measure the seven tenets in this study, the Views of Nature of Science Questionnaire (VNOS-D+), a well validated instrument for assessing students' understanding of the seven NOS tenets, was used for the present study. The VNOS-D+, which was developed by Lederman & Khishfe (2002), contains ten questions. An experienced science teacher translated the questionnaire from English into Chinese, and another experienced science teacher and an English teacher back translated the Chinese version into English. Two experienced teachers reviewed the items to ensure linguistic consistency with the original questionnaire. If there were doubts about the meaning of the questions, the question concerned would be modified to comply with the original meaning. In addition, the questionnaire was pilot tested with ten Grade 12 students who belonged to the science stream in the same school, but not studying in the biology class, to avoid any undue influence to this study. The pilot test was to ensure that the Chinese version of the questionnaire was comprehensible to students in that age range.

After the pilot test and the necessary revision to the questionnaire thereafter, the Chinese version of the questionnaire was administered to the students of the two treatment groups before the intervention. The VNOS-D+ questionnaire contains open-ended questions that focused on seven tenets of NOS. These seven tenets are *Empirical evidence*, *Observation and inference, Theory and law, Creativity and imagination, Tentativeness, Subjectivity,* and *Social & cultural embeddedness.* The VNOS-D+ questionnaire was not as lengthy as the two earlier versions, VNOS-B and VNOS-C, that required almost one hour and a half to complete. VNOS-D+ could be completed in not more than 60 minutes, with comparable validity as for the VNOS-B and VNOS-C (Lederman, 2007). There are other instruments available for measuring understanding of NOS, but they are closed-ended instruments, such as Likert-scale instruments (Tsai, 2006). Deng, Chen, Tsai & Chai (2011) indicated that these closed-ended instruments might not accurately reflect students' understanding of NOS, even though they allow quick and easy collection of numerical data for quantitative analysis. Hence an open-ended questionnaire in the form of VNOS-D+ was adopted in this study for a more accurate assessment of student understanding of NOS.

Demographic information of the participants was recorded, such as the name of participants used for selection to the semi-structured interview, as well as their age, grade level (S5 or S6), gender (boy or girl) and their biology academic performance in terms of the academic score from the previous semester. In order to protect the privacy of the students, all students' names were hidden in the result. They were assigned special codes, and the link between the name and code was stored separately in a locked office.

3.5 Research Design

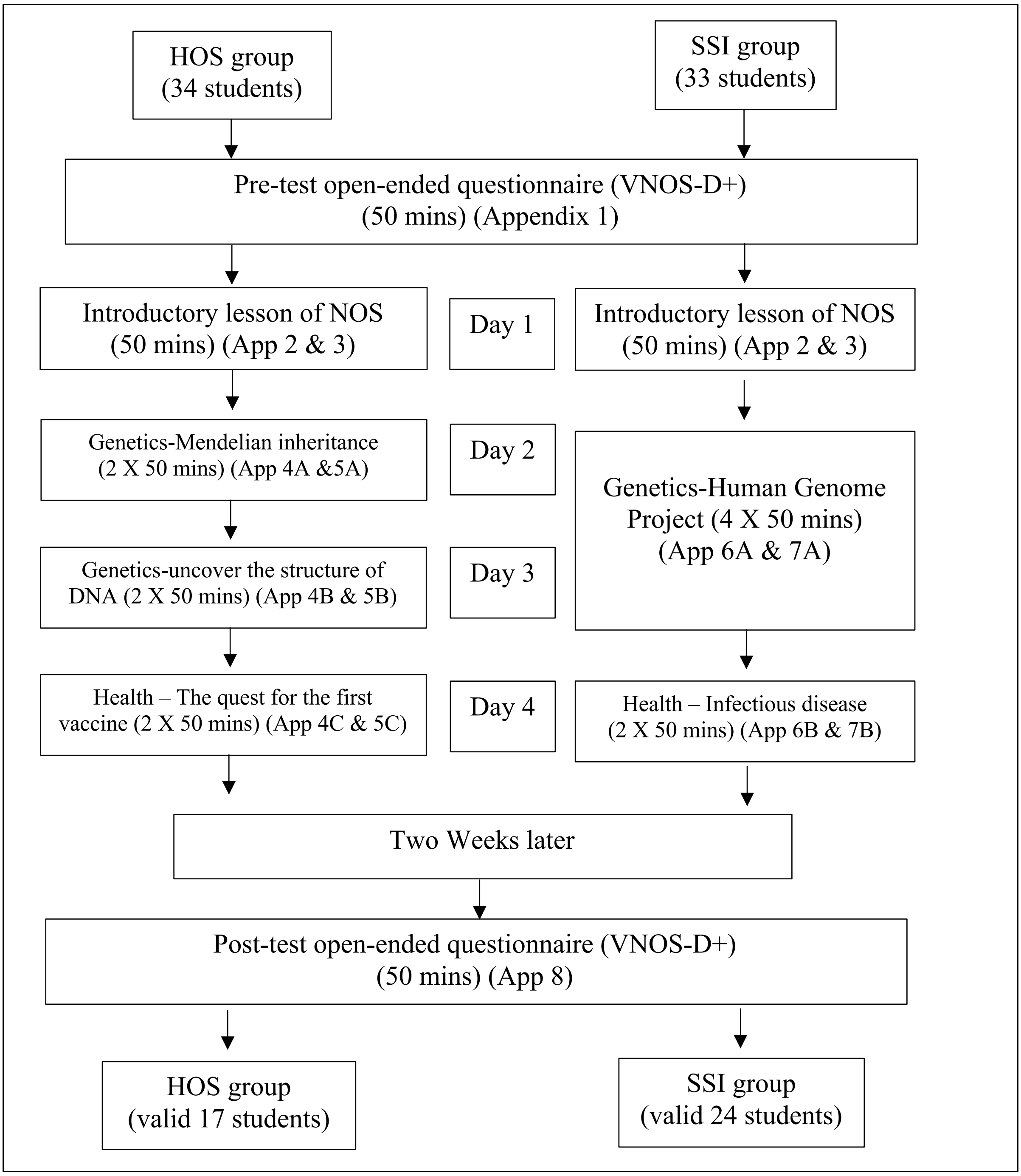
The research design is one of a quasi-experimental design involving two intact groups randomly assigned to either one of the two treatments, that is, either HOS or SSI as the teaching approach for learning NOS. A mixed method approach was adopted which involved both qualitative and quantitative methods. Demographic information was collected before the intervention, including gender, age, and biology academic performance. A pre-test and a post-test with 10 open-ended questions were administered before and after the intervention for both treatment groups. The data was then analyzed to compare the effectiveness of the two approaches in learning the seven tenets of NOS. After the intervention, several students were selected from each group to participate in a semi-structured focus group interview for further probing into their thinking of NOS, making reference to their response to their pre-post-tests.

3.6 Procedures

The secondary students in the two treatment groups participated in either one of the two intervention types, the HOS or SSI approach. All of them completed the demographic questionnaire and VNOS-D+ Pre-test (Appendix 1) within 10 and 50 minutes respectively before the intervention.

Both groups received seven lessons of interventions that lasted about 350 minutes in total for each group. The intervention time was calculated on the basis of the weighting of 1.25% to 2.5% assigned to the teaching of NOS as recommended by the HKDSE (HKEAA, 2013; HKEAA, 2014; HKEAA, 2015; HKEAA, 2016; HKEAA, 2017; HKEAA, 2018). Based on the total of 270 hours for teaching the Biology curriculum (CDC and HKEAA, 2007), 2.5% represents approximately 360 minutes in the whole curriculum. According to the school timetabling arrangement, there are 50 minutes per lesson, so the intervention was restricted to seven 50-minute lessons. Thus, the treatment time aligned closely with the designated teaching hours for NOS (Figure 3).

Figure 3 Workflow of methodology



For this study, it was decided that an explicit approach be used for both treatment groups. Bell et al. (2011) compared the effectiveness of using an implicit and an explicit approach to teaching of NOS with the use of SSI and without SSI. The tenets of NOS that they focused on are: *empirically based, tentativeness, subjectivity* and *human inference,* and the issue they employed was global warming. 75 pre-service teachers were divided into four groups to participate the intervention. These four groups were: *implicit NOS with SSI*; *implicit NOS without SSI*; *explicit NOS with SSI,* and *explicit NOS without SSI*. Pre- and post-questionnaires, semi-structured interviews, course materials and journals were collected for data analysis. The results were that teaching with SSI or without SSI played no significantly change to the learning of NOS, but teaching NOS explicitly had a positively significant effect on the learning of NOS tenets.

Khishfe and Abd-El-Khalick (2002) also conducted the study on the influence of the explicit and reflective inquiry-approach as well as the implicit inquiry-approach on primary 6 students' understanding of NOS. The two researchers also reported that explicit approach was a more effective way to deliver NOS concepts. They found that teaching chemical equilibrium using a historical approach was effective in improving students in learning NOS. Peters (2012) provided more evidence about the relative effectiveness of the explicit approach versus the implicit approach. Peters compared the explicit and implicit ways to deliver the concept of NOS to middle school students. The result was that students learnt through the explicit way significantly outperformed those learnt in the implicit way. Based on all these research evidence, this study employed an explicit way of teaching NOS for both treatment groups although different approaches were employed.

In order to ensure fairness in comparison of the two treatment groups, the researcher taught both treatment groups using the two approaches. Moreover, to minimize any bias of treatment, the teaching topics selected for both approaches were similar. The two main areas covered by the two groups were Genetics and Health. This arrangement should have removed any effect due to content that may affect the result of the intervention. To introduce the concepts of NOS in an explicit way, both groups received an introduction to NOS for about 50 minutes at the beginning of the intervention. In this 50-minute session, the seven tenets of NOS were taught with relevant contexts, such as experimentation, the wilting of seedling, Mendel's second law, the theory of Darwinian evolution, the function of cell membrane, the invention of the first microscope development, the discovery of gastric ulcer and space exploration, etc. The teaching materials for this session, designed by the researcher, were aimed to facilitate students' understanding of the different tenets of NOS. In order to avoid any biases in the understanding of NOS by either group as a result of different teaching contents, two biology scholars in the Education University of Hong Kong were invited to examine all teaching materials the researcher designed. The teaching materials for the two groups were amended according to their suggestions. In order to ensure fairness between the two groups during the intervention without bias possibly created by a sole researcher, the lesson plans produced for both treatment groups were examined by my supervisor to ensure fairness in delivering the lessons. The lesson plans for teacher's use were provided in Appendix 2, and the student worksheets were provided in Appendix 3.

3.6.1 Introductory session on NOS

First, two groups of students separately attended an introductory lesson about NOS, which was entitled "What is Nature of Science?" The term, NOS, was quite unfamiliar to them, but students were introduced to the fact that they had experienced or worked with scientific inquiry in their previous science lessons, such as designing experiments, making hypotheses, doing experiments, collecting data and drawing conclusion. Then, the seven tenets of NOS were introduced to the students one by one with detailed description and explanation.

1) "*Empirical evidence*" means science was based on experience or derived from experiments (Lederman, Lederman & Antink, 2013). Students' attention was drawn to some of the science processes they have learnt in conducting investigations, such as observing, formulating hypotheses, collecting data, analyzing data and drawing conclusion. These processes were very familiar to the students, since they learnt and practiced these processes from secondary one onward. For instance, students practiced these processes when designing and finding out the energy values of foods, proving that oxygen, fuel and a high temperature are important conditions for a fire to break out according to the fire triangle, etc. So, this first tenet was easy for students to understand as it is directly related to the development of scientific knowledge they had experienced in the classroom before.

2) "*Discrimination between Observation and Inference*" is referred to the formation of scientific knowledge based on observation and inference, but the two were different to a considerable extent. Observation usually takes the form of a descriptive statement, which directly describes the natural phenomena as informed by our sense organs (Lederman et al., 2013). For example, a seedling wilted after being illuminated by strong sunlight for a long time. By contrast, inference is a statement about the phenomenon that was not directly detected by the sense organs (Lederman et al., 2013). For example, the proposed reason that the seedling wilted due to evaporation is an inference. The notion of evaporation was inferential due to its effect on the seedlings. This example was not difficult for the students to understand as all of them had already come across the topic of plant support by turgidity in their biology lessons at secondary four.

3) "*Discrimination between Theories and Laws*" means that the development of scientific knowledge involved theories and laws. Theories and laws are different, and it was important

for students to distinguish between them. Laws are statements or descriptions of the relationship among observable phenomena (Lederman et al., 2013), such as Mendel's second law, which was the law of independent assortment in meiotic cell division. Students learnt about how homologous chromosomes are separated from each other in secondary five. By contrast, theories are inferred explanations about the observable phenomena (Lederman et al., 2013). For example, the theory of Darwinian evolution explains how one life form evolved from a simpler form. The role of theory was to guide scientific investigation and generate new research questions in the future. Students found these two examples easily acceptable.

4) "*Creativity and Imagination*"- scientific knowledge not only requires empirical inquiry for seeking evidence, and observation, but also requires the generation of explanations, which requires a lot of creativity and imagination (Lederman et al., 2013). For example, when we taught the functions of cell membrane, students knew one of the functions of the cell membrane was being selectively permeable to certain substances or molecules, but how this selective permeability is achieved in real cells? To understand this particular function of the cell membrane, scientists created the cell membrane model to explain this function of selective permeability to students. Students found this theory acceptable as it is able to explain how different types of substance move across the cell membrane with different degrees of easiness.

5) "*Tentativeness and subject to change*" refers to the notion that scientific knowledge was never absolute. Instead, it was tentative and subject to change. Since when the new evidence appeared, which might be due to advancement of technology, that allows scientists to re-examine the existing theory based on new evidence collected, or the old evidence was re-interpreted as new theories advance to shift the direction of research (Lederman et al., 2013). In the lesson, the discovery of the living cell was used as an example to deliver the concept of

tentativeness. Humans had not thought of any basic units of living organisms until after the invention of the first microscope due to technology advancement, the cell was discovered through direct observation as the basic unit of living organisms. Also, the discovery of the universe and the continuous growth of astronomical knowledge is a result of the invention of more and more advanced telescope that extended human capability to observe objects or phenomena farther and farther away in the universe.

6) "*Subjective or theory-laden*" refers to the notion that scientific knowledge was subjective, since it was constructed by scientists. Scientists created the knowledge based on inference in their minds, what they learnt before, what they expected, and what they believe in. All of these might affect the formation of scientific knowledge (Lederman et al., 2013). For example, in teaching the discovery of the cause of gastric ulcer under the topic of digestive system at secondary four, the focus is on the production of acidic juice in the stomach. As scientists knew that, there were acids in the stomach, which could stop bacterial growth, they suspected the gastric ulcer was due to the stomach being exposed to an acidic environment. This had led them to reject the possible cause by bacteria. However, a doctor, as guided by his subjective hypothesis about the bacterial origin of peptic ulcer, did an experiment by doing a biopsy on a patient that allowed him to draw out some bacterial sample and cultivate them at a suitable environment. The result was that bacteria were found in the patient stomach, thus verifying his hypothesis. However, although the generation of hypotheses or theories could be subjective, the collection of evidence and the relevant argumentation that lead to the validation or refutation of subjective ideas is expected to be done in an objective manner.

7). "*Social and cultural embeddedness*". Scientific knowledge interacts with both society and culture throughout history. Scientific knowledge was affected by many elements, such as, political factors, socioeconomic factors, religious factors, philosophy and power structures. The scientific establishment and community were influenced by culture (Lederman et al., 2013). For example, space exploration and relevant scientific research have been driven by society or political regimes at different points in history and until now. As a result, many research papers or articles were generated about space during that time.

All of these NOS ideas or tenets were explained explicitly to students in both groups with examples and case illustrations, with the support of various teaching materials so as to present the proper concepts to students. This introductory session was followed by the use of either one of the two teaching approaches, HOS or SSI, to develop a more detailed discussion and understanding about NOS with the students in the respective treatment groups.

3.6.2 Description for the HOS Approach

In the HOS treatment group, the students were requested to work in groups of four or five. They were taught by the teacher with the aid of various reading materials to introduce relevant topics. The students worked together to discuss these relevant topics, search for the extra-relevant information online by using search engines, produce a presentation to other students, complete the worksheet, role-play or discuss among students within six sessions, each lasting 50 minutes during the intervention process. The teacher designed the lesson plan for his own use, which was provided in Appendices 4A, 4B & 4C. The lesson worksheets designed for students' use in the HOS group were provided in Appendices 5A, 5B & 5C. All the teaching materials were adapted from local Biology textbooks with necessary revision by the researcher. The topics taught to this group were shown in table 3.

In the first lesson, the students were taught the concepts of NOS under the topic of Genetics, anf Mendel's experiment was used as the storyline. The lesson started by teaching about the way to discriminate the two terms - *character* and *characteristic*. Students were then focused on the term of *observation* when the red flower plant was cross-pollinated with the white flower plant. The teacher discussed the science processes involved in Mendel's experiment, from his observation of non-pink flower being obtained from crossing white with red flowers, to his hypothesis that refutes color mixing as a result of cross-pollination, and from data collection to analyzing data and drawing conclusions. In this inquiry process, students were taught the concept of hypothesis, and the hypothesis Mendel made, which was that each gamete might carry only one hereditary factor,. Students were led through the *series of experiments* Mendel conducted, which led him to prove his original assumption or hypothesis that each gamete carried only one inheritance factor.

Another conclusion Mendel drew is that only a single inheritance factor could express itself in the next generation, masking the characteristic of the other factor. In this way, he conceived the notion of dominant and recessive characters. During the lesson, students were also exposed to the arduous process of argumentation with other scientists. Mendel's idea was initially rejected by the scientific community before he obtained sufficient evidence to support his assertion from his experiments conducted later on. Another impeding factor is that scientists tended to adhere to the knowledge commonly accepted by the scientific community during that time, which underscores the importance of the *influence of society and culture* on scientific development. Mendel's theory was accepted only until the meiotic cell division was confirmed.

At this juncture, Mendel's first law, which describes the occurrence of hereditary factor in pairs to decide on the character of organism, was used to distinguish between the meaning of *laws* *and theories* to students. Laws are statements or descriptions of the relationship among observable phenomena, whereas theories were inferred explanations about these observable phenomena. Finally, there were some discussions among students on the characteristics of Mendel that brought him success in genetics. Students' answers include his curiosity and observation that led him to investigate why pink flowers did not occur after red and white flowers were cross-pollinated, and his *creative and imagination* that caused him to conceive the presence of hereditary factors in gametes.

In the second lesson, students were taught the concepts of NOS in the context of Genetics. The discovery of the structure of DNA was used as the stem of the story. The teacher talked about how DNA structure was discovered. First, in 1869, Fredrick Miescher extracted DNA from a living sample, but he knew nothing about the components and functions of DNA. Then, at 1929, another scientist identified the components of DNA as deoxyribose, phosphate and four nitrogenous bases. In 1940s, many scientists had proved from their *experimental findings* that DNA was the hereditary substance. So, research on DNA was a hot issue during that period of time. This could bring out the idea that the development of scientific knowledge was under the influence of *society and culture*. Subsequent studies focused on how the components formed the structure of DNA.

In 1950s, there were two groups of scientists in UK competing with each other to unveil the structure of DNA. In 1953, Maurice Wilkins and Rosalind Franklin used X-ray crystallography to produce the scattering of DNA. Their finding eventually contributed to James Watson and Francis Crick's discovery of the 3-dimensional double helical model of DNA. From this story, students could appreciate the *creativity and imagination* of Watson and Crick in producing that spectacular 3-dimensional model of DNA. With the increased amount of research devoted to the study of DNA, the knowledge of DNA kept changing from time to time. Finally, even though scientists in 1950s obtained the same data about DNA, it is interesting to explore why different scientists drew different inferences or conclusions. This discussion could effectively bring forth *subjectivity* as one of the tenets of NOS, which influences the development of scientific knowledge.

In the third lesson, the discovery of the first vaccine was used as the main storyline to deliver the concepts of NOS. In 1796, Edward Jenner carried out the famous experiment on an eight years old boy. He inserted some cowpox pus materials into the healthy boy's arm. He tested his theory that milkmaids who suffered from the mild disease of cowpox had never infected with smallpox because cowpox can confer immunity against smallpox. Finally, the result of the healthy boy remaining healthy proved that the little boy inoculated with cowpox was immune to smallpox. However, Jenner's finding was not accepted by the public at that moment, since *society* at that time was against inoculating a healthy person with materials taking from an animal. But finally, the benefits brought about by vaccination has become well established, thus proving his theory was correct. Here students could see the importance of Jenner's *creativity and imagination* in testing his theory on the little boy. Also, his work was obviously influenced by people and *society* at that time, which discouraged him to inject animal materials into healthy persons. Asides from these factors, students were expected to learn how to make observation, create hypothesis, conduct experiment, collect data and draw conclusion.

3.6.3 Description of the SSI approach

The students in the SSI group were requested to work in groups of four or five, they were taught by the teacher with the aid of different readings materials, online search and class presentations on relevant topics, role-plays and class discussion. Just like the HOS group, all of these activities took place within six 50-minute sessions during the intervention. The lesson plan for teacher's use was provided in Appendices 6A & 6B. All the teaching materials were adopted from the learning kit (Appendices 7A & 7B) developed by the Education Bureau with necessary amendment by the researcher and reviewed by science education scholars at the Education University of Hong Kong. The topics discussed were showed in table 4.

The topics chosen for the SSI group were the same as those for the HOS group so as to minimize the effect of contents on the learning of NOS. Genetics and health were chosen as the topics.

In the first lesson, students were provided with an article on the human genome project and how this project initiated genetic screening on fetus. Students were led to discuss the issue of people debating whether genetic screening of the fetus could be used to prevent the inheritance of genetic diseases. Students discussed what should be done if the gene causing those diseases were found at the fetal stage. Should the fetus be aborted or not? During the lesson, some specific terms related to NOS were introduced, e.g., *law and theory*, students were asked if an abnormal gene is found inside the fetus, it might suffer from hereditary disease. Is this a law or a theory?

This was followed by group discussion and presentation on whether the case presented a law or theory. In order to consolidate the concept of law and theory in students, the teacher reiterated the meaning of law and theory in the introductory lesson as in the HOS group. Laws were statements or descriptions of the relationship among observable phenomena. By contrast, theories were inferred explanations about the observable phenomena. Hence, the presence of abnormal gene causing disease is to be considered as a law. A theory is a plausible explanation of how the gene causes the disease. Students also talked about the issue of genetic screening as many medical centers are offering prenatal genetic screening service to avoid hereditary diseases in the newborn. This was an example in which the development of science is influenced by *society and culture*, which push scientists to search for abnormal genes to eliminate hereditary diseases.

The second lesson continued with the discussion on how the human genome project helped to elicit relevant NOS concepts. The teacher led students to discuss how to prove the presence of abnormal genes that cause diseases. They needed to make use of science process skills to *design experiment* to prove their hypothesis or theory. So, it was a time for them to consolidate their understanding of how science processes have led to the development of scientific knowledge. Teacher told students that prenatal genetic screening was dangerous to both the fetus and mother, since it was an invasive sample collection method, which might result in infection or abortion. Students were asked to develop a safer method to prevent the transmission of hereditary diseases. They discussed this in the group and proposed their own ideas to prevent hereditary diseases, such as, genetic screening of sperms and eggs. The aim was to stimulate students to use their *creativity and imagination* to suggest new methods and help them develop the *concept of tentativeness*, as their ideas might come true one day.

In the third lesson, infectious diseases were used as a stem to deliver the concept of NOS. The ways in which Dengue fever and Avian Flu spread were discussed. For Dengue fever, students needed to discuss about the transmission of the disease by mosquitoes serving as vectors. Students first focused on the life cycle of mosquitoes and then raised solutions to prevent the spread of Dengue fever. Students suggested termination of the life cycle of mosquitoes to stop their breeding. Then teacher challenged them how to prove the life cycle of mosquitoes stated on their worksheet was true. This was to stimulate students' concept of *observation* and collecting *evidence by experiments*. They needed to collect mosquitoes and design an experiment to show mosquitoes relied on water to reproduce. Students were presented with two sets of data about the occurrence of both local cases and imported cases of Dengue fever from outside Hong Kong from 1994 to 2006. They were then assigned into two groups to discuss the trend of the outbreak of Dengue fever in Hong Kong, and to come up with their own conclusion. The aim was to lead students to realize that even with the same set of data, the conclusions drawn by different groups might be different as there was more than one way to interpret the data. This is due to the different mindsets of scientists, which forms the basis of the *subjectivity* tenet of NOS.

For the issue of Avian influenza, students were provided with articles about the problem of Avian flu in Hong Kong and how the government addressed the problem. They were asked to comment on the massacre of all Avian influenza infected birds and suggest another way to stop the spread of the disease. They were then led to discuss how to confirm whether a bird is infected with the disease. This was to provide an opportunity for the students to connect the concepts of NOS in their minds and apply them to the issue, leading to resolution of the problem.

All the lessons were video-recorded to allow the researcher to observe the lesson to ensure the lesson plan was followed for the two treatment groups. All lesson worksheets and handouts were collected to check the students' learning progress. Students' attendance was also recorded for compiling the number of valid data after the intervention.

Table 3 Teaching plan for the HOS intervention

Topic	Brief Descriptions	Duration	Ideas about NOS
Genetics-Mendelian inheritance (App 4A & 5A)	A historical approach of how Gregor Mendel carefully performed breeding experiments to investigate the mechanism of inheritance in pea plants.	2 x 50 minutes lesson	• (5) Hypotheses are testable tentative explanation of natural phenomena. • (7) Socially and culturally embedded in science. • (3) Laws are descriptive sentences of relationships among observable facts. Theories are the explanation of those relationship.
Genetics-Uncover the structure of DNA (App 4B & 5B)	A historical episode of the scientific thinking processes experienced by Chargaff, Wilkins, Franklin, Watson and Crick in their quest to uncover the structure of DNA.	2 x 50 minutes lesson	• (2) The building of DNA model requires observations, background knowledge, logical reasoning and creative imagination. • (5) Tentative and subject to change. • (6) Scientists having the same set of data may not arrive at the same conclusions.
Health - The quest for the first vaccine (App 4C & 5C)	A historical episode of Edward Jenner's observations, hypothesis and experiments in the quest for a vaccine against smallpox.	2 x 50 minutes lesson	• (1) The main processes for scientific inquiry are: making observations, asking a question, proposing a hypothesis, testing the hypothesis, drawing and evaluating conclusions. • (4) Doing science requires creativity and imagination. • (7) Science is socially and culturally embedded.

Table 4 Teaching plan for the SSI intervention

Topic	Brief descriptions	Duration	Ideas about NOS
Genetics - Human Genome Project (HGP) (App 6A & 6B)	A socio-scientific issue that is conducive to the use of the HGP to predict the chance of transmitting hereditary diseases in the next generation.	4 x 50 minutes lesson	• (7) Socially and culturally embedded. • (5) Tentative and subject to change. • (1) Science is empirical based. • (3) Laws are descriptive sentences of relationships among observable facts. Theories are the explanation of those relationship • (4) Doing science requires creativity and imagination.
Health - Infectious Disease (App 7A & 7B)	A socio-scientific issue about two infectious diseases, Dengue fever and Avian influenzas. Students use the newspaper clips to discuss about the sources of disease and preventive method.	2 x 50 minutes lesson	• (7) Socially and culturally embedded. • (1) Science is empirical based. • (2) Science is observation and inference. • (6) Scientists having the same set of data may not arrive at the same conclusions.

After conducting the seven lessons of intervention in the two treatment groups, all students were required to complete the post-test VNOS-D+ (Appendix 8) within 50 minutes.

For fairness sake and to cater to the learning needs of the students, identical lessons were conducted for both treatment groups sometime after the intervention to allow the students to go through the seven tenets of NOS again to help them prepare for the HKDSE. All students were led to discuss past examination questions on NOS and how to answer them properly.

3.7 Qualitative Data

Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) reported that 15-20% of participants would form an interview sample with sufficient representativeness. According to their suggestion, five students (29%) from the HOS group (17 students) and six students (25%) from the SSI group (24 students), who showed different degrees of changes after the intervention from each treatment group, were invited to participate in a semi-structure interview. As guided by the students' responses obtained from the pre-post-tests, the interviews were intended to reveal students' perceived influences of a particular approach on their views on NOS, and also to triangulate the data obtained from the questionnaire responses. The interview was conducted on an individual basis. References were made to, their response to the VNOS-D+ questionnaire and a pre-set interview protocol. All interviews were audio-recorded by smart phone for transcription and analysis, and were limited to 10 minutes each. During the interview, selected students were required to clarify and elaborate their ideas on the questionnaire. The interviewer tried not to direct or restrict the students in talking about their ideas. If necessary, follow-up questions were asked to further elicit student's ideas. Students were allowed to interact freely, question or seek clarification from the interviewer during the interview. The researcher served as a facilitator to encourage the interviewees to express their views and guide them to explore their own ideas, which might provide useful data for answering the research questions. Field notes were kept and used as a source for validity checks during the discourse analysis in the lesson, as well as the original responses of students to the questionnaires.

The researcher used the following semi-structured protocol to interview the students:

Here are your original ideas in the questionnaire. You can keep these ideas to yourself and refresh your memory concerning your original ideas…… can you elaborate more on these….

I would like you to restate your idea about ...... to what extent do you agree or disagree with the sentences: ……

Can you provide more examples to explain your idea about ….?

To what extent do you trust the weather forecast? Why?

How does learning about the history of the development of genetics or discussion about the human genome project influence your views on a particular tenet of NOS?

The interview was audio recorded by smart phone and transcribed verbatim for analysis to provide more in-depth understanding of the respondents' view.

The intervention in both approaches during the lesson was video-recorded for subsequent classroom observation. As the lessons were taught by the researcher, it was impossible for him to observe himself at the same time, so watching the videos after the lessons could provide a means for checking the implementation of the teaching approach as planned. It was used to check how the teacher might have influenced student ideas about the different tenets of NOS.

3.8 Quantitative Data

There were 10 items in the VNOS-D+ questionnaire (Lederman & Khishfe, 2002), with each item reflecting students' understanding of the different tenets of NOS. An experienced science teacher was invited to read the responses of each participant and rate their responses into three categories (informed, mixed and naïve) according to a set of rubrics prescribed by the researchers that created the instrument. Rating was also done independently by the researcher. Then the teacher and the researcher discussed their ratings together, as so to gain a consistent assessment for each student's responses. Students' understanding of the seven tenets of NOS were categorized into three different categories or levels: "informed", "mixed" and "naïve". The scoring rubrics (Cofré, Vergara, Lederman, Lederman, Santibáñez, Jiménez & Yancovic, 2014, p.770) were as follow:

- Informed: The responses clearly showed that the student's opinion reflected the recommended view. It gained 2 points.
- Mixed: The answer was aligned with the recommended position but was not fully developed or expressed or it was simply a reiteration of the definition provided. It gained 1 point.
- Naïve: The answer showed that the student's opinion was not aligned with the recommended position. It gained 0 point.

The analysis of the questionnaire responses based on the rubrics (Cofré et al., 2014) were discussed below. Table 5 shows a summary of the NOS tenets revealed by students' responses to respective question items.

Table 5 Summary of the questions in VNOS-D+ assessing the seven NOS tenets

NOS tenets	Question number for assessment of the tenets
Empirical based	2, 4d
Observation and Inference	1, 3, 4a, 4b, 5, 6
Theory and law	8
Creativity and imagination	2, 4b, 5, 6, 7
Tentativeness	1, 3, 4b, 9
Subjectivity	2, 3, 4c
Social & Cultural embeddedness	10

Item 1 -*"What is Science?"* - is an ice-breaker to stimulate the students to start brainstorming about what science they knew before. However, students may bring up issues that related to the certainty of knowledge (tentativeness) and objectivity in describing science, or any other aspects of NOS.

Item 2 (Table 6) -*"What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject / disciplines (arts, history, etc.)?"*. This question is more specific than item 1. The aims are to evaluate the students' ideas regarding science as a subject to address problems about the natural world, the function of science in providing explanations for natural appearance, and how experimental evidence in science helps to distinguish science from other "ways of knowing". It is often found that a common misunderstanding concerned the use of the scientific method as an objective procedure to gain the knowledge. This item was also expected to reveal students' ideas about creativity, empirical basis, and subjectivity. If the students were able to provide in-depth explanation on the above three aspects, their responses may be rated to informed.

Table 6 Assessment rubric for Item 2 of VNOS-D+

NOS	Naïve	Mixed	informed
Empirical basis	Express the view only	Partially show the difference in science	Show complete difference between science and non-science
Creativity & imagination			
Subjective			

For the item 3 (Table 7), *"Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example."*. It is expected students can provide the answer about the tentativeness, but it may also yield some data on observation, inference, and subjectivity.

Table 7 Assessment rubric for Item 3 of VNOS-D+

NOS	Naïve	Mixed	Informed
Tentativeness	Express view only	Partially express the ideas, such as technology advancement / example raised	Completely express the ideas such as technology advancement and correct example raised
Observation & inference			
Subjectivity			

For the item 4a (Table 8), *"How do scientists know that dinosaurs really existed? Explain your answer."*. It is expected students will provide the answer related to observation and inference since they knew dinosaurs existed through the discovery of their fossil records.

Table 8 Assessment rubric for Item 4a of VNOS-D+

NOS	Naïve	Mixed	informed
Observation & inference	Just express "Fossil record"	Partially express the ideas	discover the fossil record and figure out the dinosaur

For the item 4b (Table 9), *"How certain are scientists about the way dinosaurs looked? Explain your answer."*. It is targeted at tentativeness and inference, since the scientists based their interpretation and prediction mainly on the discovery of fossil record.

Table 9: Assessment rubric for Item 4b of VNOS-D+

NOS	Naïve	Mixed	Informed
Tentativeness	Just express view	Partially explain and some wrong ideas found	With completed explanation to prove
Observation & Inference			
Creativity & imagination			

For the item 4c (Table 10), *"Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what caused this to happen. Why do you think they disagree even though they all have the same information?"*. This question was to assess students 'ideas about inference and subjectivity, since some students may explain the reason based on their prior learning or experience.

Table 10: Assessment rubric for Item 4c of VNOS-D+

NOS	Naïve	Mixed	informed
Observation & inference	Express view only	Express view with partial explanation	Express view with completed explanation
Subjectivity			

For the item 4d (Table 11), *"If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer."*. It was to assess students' understanding of the empirical basis of science. They are required to answer by raising a method to prove the hypothesis.

Table 11: Assessment rubric for Item 4d of VNOS-D+

NOS	Naïve	Mixed	informed
Empirical basis	Just express the idea without elaboration	Express the ideas with incomplete elaboration	Express the ideas with complete elaboration

For the item 5 (Table 12), *"In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns. (a) Do you think weather persons are certain (sure) about the computer models of the weather patterns? (b) Why or why not?"*. It is expected students will suggest that the computer models of the weather pattern are tentative, which are derived from observation and inference by the weather persons.

Table 12: Assessment rubric for Item 5 of VNOS-D+

NOS	Naïve	Mixed	informed
Tentativeness	Weather pattern is tentativeness	With partial explanation of how the weather forecast may change	With complete explanation of how the weather may change due to the weather forecast is affected by many variables
Observation and inference	By weather person	With partial explanation of experience of weather person	With complete explanation of experience of weather person

For the item 6 (Table 13), *"The model of the inside of the Earth that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth exactly represent how the inside of the Earth looks? Explain your answer"*. Again, the focus of assessment is on observation & inference, but it may also yield data on creativity & imagination.

Table 13: Assessment rubric for Item 6 of VNOS-D+

NOS	Naïve	Mixed	informed
Observation & inference	Just express inaccuracy	With partial explanation due to observation & inference	With complete explanation of observation & inference
Creativity & imagination	Just express inaccuracy	With partial explanation due to creativity & imagination	With complete explanation of creativity & imagination

For the item 7 (Table 14), *"Scientists try to find answers to their questions by doing Moreover, Do you think that scientists use their imaginations & creativity when they do these investigations / experiments? (a) If NO, explain why. (b) If YES, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination & creativity? Give examples if you can."*. It is expected students will give the answer about creativity and subjectivity, since the scientists may base on their personal will to make the hypothesis.

Table 14: Assessment rubric for Item 7 of VNOS-D+

NOS	Naïve	Mixed	Informed
Creativity & Imagination	Just express the view	With partially correct or incomplete examples to illustrate	With correct or complete examples to illustrate
Subjectivity	Just express the view	With partially correct or incomplete examples to illustrate	With correct or complete examples to illustrate

The item 8 (Table 15), *"Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example"* helps to realise how students know the difference between theories and laws. The common misunderstanding of the presence of the hierarchical relationship between laws and theories is often discovered. Students may perceive the existence of a process in which a scientific theory will become a law if the theory is finally proven to be true.

Table 15: Assessment rubric for Item 8 of VNOS-D+

NOS	Naïve	Mixed	Informed
Laws and Theories	Provide partially correct meaning of laws and theories with no examples	Provide partially correct meaning of laws and theories Or Provide partially correct examples	Laws are the description of the relationship between natural phenomena. And provide with correct example Theories are the explanations of the relationship between natural phenomena. And provide correct example

For the item 9 (Table 16), *"After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example."* It is quite a straight-forward question to test the students' understanding of the idea that theory may change based on the discovery of new evidence, i.e. scientific knowledge is tentative.

Table 16 : Assessment rubric for Item 9 of VNOS-D+

NOS	Naïve	Mixed	Informed
Tentativeness	Just express the view "change"	"Change" with partially correct explanation	"Change" with fully correct explanation

For the item 10 (Table 17), *"Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide examples."* It is aimed to assess whether students are aware that science is related to society and culture, which implies the social and cultural embeddedness of science.

Table 17 : Assessment rubric for Item 10 of VNOS-D+

NOS	Naïve	Mixed	Informed
Social & cultural embeddedness	Just express YES	YES With partially correct and clear explanation	YES With correct and clear explanation

3.9 Methods of Data Analysis

The pre- and post-test of VNOS-D+ were analyzed to generate profiles of students' ideas regarding the seven different NOS tenets. The same scoring rubric provided by the questionnaire was used in this study. The assessment procedure involved the classification of students' responses into three categories - "informed", "mixed", or "naïve"- for each NOS tenet. To classify a student's ideas about a NOS tenet, if a response clearly showed that the student's opinion reflected the recommended opinion, the response was coded as "informed" (a value of 2). If the answer was aligned with the recommended position but was not fully developed or expressed or it was simply a reiteration of the definition provided, it was coded as "mixed" (a value of 1). If the answer showed that the student's opinion was not aligned with the recommended position, the answer was coded as "naive" (a value of 0) (Cofré et al., 2018, p.253).

Campbell & Stanley (1963) suggested that for non-equivalent quasi-experiment and pretest-posttest control group design, *t*-test is commonly used for quantitative data analysis. It could test the pretest-posttest difference in both the intervention group and the control group respectively. If the findings from the intervention group are statistically significant, but those from the control group are statistically insignificant, it could be concluded that the intervention had an effect on the subject. However, such test does not allow any direct comparison between the intervention and control groups. Therefore, for part of this study, the analysis of gain scores and covariance are preferred to the use of *t*-test. The gain scores of each group from the pre-test to the post-test were calculated, followed by the calculation of the *t* between the two treatment groups on the gain scores. More specifically, this study used paired *t*-test to answer the RQ1 and ANCOVA to answer the RQ2 and 3.

For the RQ 1 (Could the SSI and HOS teaching approaches enhance Hong Kong senior secondary students' understanding of the major tenets of NOS?), the paired *t*-test was used to test for the difference in learning of NOS before and after students received input either through the SSI or HOS teaching approach. If significant differences were found in any of the two groups, it could be inferred that the respective teaching approach was able to help students in learning NOS. if there was no significant difference between the pre- and post-test, the opposite is true, that is, the teaching approach was unable to help students in learning NOS. First, the paired *t*-test was used to test for the difference in learning of NOS by SSI and HOS respectively. Then, the score gains in each tenet after teaching with the SSI or HOS approach were studied to establish any correlation among students' learning of those seven tenets by Pearson's correlation test.

For the RQ 2 (Which approach, the SSI approach or HOS approach, is more effective in helping Senior Secondary Biology students develop more informed conceptions of the major NOS tenets?), it was aimed to determine whether there were any differences in the mean scores of the seven tenets of NOS after the intervention. However, previous knowledge of participants might have to a certain degree interfered with the intervention. To control for the possible effect of the differences in pretest score on the post-test score, ANCOVA was employed, using the pretest score as the covariate, the SSI group and the HOS group as the independent variables, and posttest test score as the dependent variable. The technique of ANCOVA combined regression with analysis of variance, which is a statistical control technique to treat the pretest scores as the covariate (Bonate, 2000). To facilitate statistical analysis, the scoring rubric of "informed", "mixed" and "naive" were converted into "2" for informed view, "1" for mixed view and "0" for naïve view. According to Dimitrov & Rumrill (2003), ANCOVA could reduce the error variance and eliminate systemic bias. It has been extensively used as a statistical method for non-randomized design. ANCOVA could adjust the posttest means for differences among groups based on the pretest score, since such differences are commonly found between intact groups.

For the RQ 2, the possible reasons for improvement or hindrance to the learning of NOS might be inferred from the written responses, students provided in the pre-test and post-test questionnaire, and the verbal response transcribed from the semi-structured interview. Students' response to the VNOS-D+ open questions in the pre-test and post-test were first matched to the three levels: naïve, mixed and informed. These views were then transformed into numerical scores with "0" denoting naïve; "1" for mixed and "2" for informed views to facilitate the quantitative analysis.

Apart from the quantitative analysis of the students' numerical scores, the written responses of the students to the questionnaire were also subject to content analysis. The analysis involved a two-step process – categorization of themes, and coding. All responses from students in both questionnaires were typed into electronic version from hardcopy, so as to facilitate the keyword searching by using Microsoft Excel search function. Then both questionnaires were read to identify recurrent themes, for example, concepts that occurred in the questionnaire quite frequently. Additionally, concepts or ideas underlying the students' responses to the questionnaire or their utterances in the interview were also noted. Relevant keywords were used in Microsoft Excel to search for all the responses, so as to ensure report of the theme was reliable. All the themes identified were presented in table form and illustrated with relevant utterances or statements extracted from the responses.

For the interview, a protocol was formulated to help students express their own ideas about the process of learning NOS. The transcribed dialogues were analyzed to find out the reasons that facilitated or hindered the learning of NOS. The content analysis of the interview transcripts also followed a two-step process - coding and interpretation. All data from the semi-structured interviews was audio-recorded and transcribed for qualitative analysis. All scripts were read through by the researcher to look for any major themes generated from the interview. The themes were the ideas raised or expressed by the students. These themes generated from the semi-structured interviews were then compared with those generated from the written questionnaire as a means of triangulation. This process also served to synthesize the data to generate more insights into the findings.

For the RQ 3 (Are there any influences of gender or biology performance on the students' learning of NOS using either approach?), the two-way ANCOVA was used to examine differences in learning outcomes regarding students' understanding of different tenets of NOS between two different teaching approaches, HOS and SSI. This technique was also used to analyze the difference in learning outcomes between the high and low biology achievers over time (from pre-test through to post-test). Therefore, in this study the two independent variables were teaching approaches (with two groups: "SSI" and "HOS") and biology performance which were their final examination scores. The dependent variable was the post-test score, and the continuous covariate was the pre-test score. The ANCOVA could ascertain statistically whether any difference in the effect of the two teaching approaches on student NOS learning was due to their difference in pre-test performance, that is, their prior understanding before the treatment.

Additionally, the Pearson correlation coefficient was used to analyze and find out the relationship between students' biology performance and their learning of the various tenets of NOS in senior secondary Biology students. The value for the Pearson correlation ranges from -1.00, which means strongly negative correlation, to 1.00, which means strongly positive correlation. If the value is 0, it means there is no correlation between the two variables.

For this RQ, the two-way ANCOVA was also used to examine differences in the learning outcomes in terms of students' understanding of the different tenets of NOS between two different teaching approaches (HOS and SSI) and any possible gender difference (boys and girls) over time (pretest and posttest). For this part of the analysis, the two independent variables were teaching approaches (with two groups: "SSI" and "HOS") and gender ("male" and "female"), the dependent variable was the post-test score and the continuous covariate was the pre-test score. This analytical method was aimed to find out whether the effect of the two teaching approaches was different for different gender of the students.

All data were analyzed using the Statistical Packages for Social Sciences (SPSS) computer software (version 25). A significant level of 0.05 was set for statistical analysis. The independent variables in this research were defined as teaching approaches, genders, and performance in biology. The dependent variables in the study were defined as the learning outcome in terms of students' understanding of different tenets of NOS, including the post-test scores and gains in score.

Triangulation of various data sources from pre- and post-tests, semi-structured interviews, and students' lesson performance could help to enhance the validity of the findings. It was supposed that students would deliver more comprehensive responses on certain aspects of the understanding of NOS during the interviews than the written part of questionnaires. No a priori hypotheses or classifications were expected so as to maximize sensitivity to the displays that arose from the data.

3.10 Summary

Students in the school participating in this study have obtained consents from their parents and the school principal. Grade 11 and Grade 12 students were invited to participate in this activity during the summer vacation. The study lasted five days, including pre-test, intervention, and post-test. After either treatment, some students were selected to participate in a semi-structured interview for the researcher to come up with a more holistic picture of their learning over the period of intervention. In order to ensure fairness across the two groups, the period of intervention in terms of lesson hours was set at 50 minutes per lesson for six lessons for both treatment groups. Cantonese was used as the main classroom language for both treatment groups, with learning materials written in Chinese. As some students were using English as the medium of instruction in their regular Biology lessons, and they would take the HKDSE Biology examination in English, the learning materials were also supplemented with English vocabularies for some specific terms for both treatment groups. The use of Cantonese as the main classroom language for the treatment was because all the participants were native Chinese. Using Chinese would effectively remove the language barrier for all students.

For the data analysis, the quantitative data collected from the VNOS-D+ questionnaire was analyzed by the paired *t*-test to gauge the effectiveness of using either HOS or SSI in delivering the concepts of NOS from their post-test and pre-test results respectively. The data for both teaching approaches were then taken together to compare their effectiveness in delivering the concept of NOS by using ANCOVA, which could reduce the error variance and eliminate systemic bias for the nonrandomized design adopted by the present study. The statistical technique of ANCOVA was used to adjust the posttest means of the two groups using the pretest score as the covariate, a common practice for addressing the difference in pre-test scores between intact groups. The items used in the pre-test were the same as that in the post-test. For the qualitative data analysis, the semi-structured interview data were examined by the researcher through the generation of themes and systematic coding to develop a more detailed and in-depth picture of student learning. The same qualitative analytical approach was applied to the students' open response to each item of the post-test questionnaire, with a view to identifying more detailed thoughts of the students about NOS, as well as motivating or impeding factors that might have influenced students learning of NOS. The use of both quantitative and qualitative methods to collect and analyze data could ensure data triangulation and maximize the sensitivity of the study.

4 Data Analysis and Results

4.1 Introduction

Based on a mixed methods approach, qualitative and quantitative data were collected and analyzed by the researcher. 67 participants joined the study and completed the pre-test, 34 for HOS and 33 for SSI. However, not all of them completed the whole process of the study, that is, from the pre-test through the six 50-minute lessons to the post-test. Some students skipped the pre-test or post-test, and some skipped one or three lessons due to absence from class. Since they did not complete the whole process of the study, their data and results were treated as invalid, and hence omitted and not to be used in this study. Altogether there were 41 valid results in this study, that is, those students who had completed the whole study process. There were 24 students with 9 males and 15 females in the SSI group, with the mean age of 16.4. And there were 17 students with 8 males and 9 females in the HOS group with mean age of 16.8. The percentage of valid data collected in HOS was 50% and that in SSI was 72.7%.

The pre- and post-test data collected from the VNOS-D+ questionnaire was analyzed to assess the level the students had reached with respect to each of the seven tenets according to the rubric provided by the instrument. The assessment procedure involved the classification of students' responses into three categories - "informed", "mixed", or "naïve"- for each NOS tenet. To classify a student's ideas of a NOS tenet as "informed", the responses clearly showed that the student's opinion reflected the recommended opinion. If the answer was aligned with the recommended position but was not fully developed or expressed or it was simply a reiteration of the definition provided, then the idea was classified as "mixed". An idea was classified as "naïve" if the answer showed that the student's opinion was not aligned with the recommended position (Cofré, et al., 2014; Cofré, Jiménez, Santibáñez & Vergara, 2016; Cofré, Santibáñez, Jiménez, Spotorno, Carmona, Navarrete & Vergara, 2018). Tables 18-24 presented examples about the categorization of responses to the seven tenets NOS.

Table 18 Examples showing how students' responses regarding the empirical basis tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Empirical basis - Scientific knowledge is based on experience. It is also based on and derived from experiments. VNOS-D+ Q4d *"If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer."*
Naïve views	2568* Post-test: To convince other. Researcher's comment: This student only repeated the question and did not provide any new idea or knowledge.
Mixed views	2574* Post-test: To find out evidence to prove the idea, and to reject other theory. Researcher's comment: This student knew he should provide the evidence to prove the claim, but he did not provide an explanation to his answer.
Informed views	2560* Pre-test: To find out the concrete evidence to prove the idea. For example, one believed that dinosaurs were destroyed by meteorite and caused extinction, .If he could find some pieces of meteorites nearby the fossil record of dinosaurs, this might be the evidence to prove his ideas. Researcher's comment: This student knew he should provide concrete evidence to prove the idea, and also provided examples to explain his answer clearly.

** the student's identification number in questionnaire*

Table 19 Examples showing how students' responses regarding the observation & inference tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Distinction between observation and inference - Scientific knowledge is based on observation and inference. There is qualitatively distinction between them. Observation can be directly accessible to the senses, such as eye; whereas inference can only be identified by its expression or manifestation. VNOS-D+ Q6 "*The model of the inside of the Earth that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth exactly represent how the inside of the Earth looks? Explain your answer.*"
Naïve views	1623* Pre-test: Yes. Since it described the layers of the earth very clearly and detailed. Researcher's comment: The student just believed the knowledge without any other support. Since the reason to push him to believe was the clear and detailed description without any other evidence to support.
Mixed views	1527* Post-test: We cannot believe that. Since no people have been there before to see the internal structure of the earth, they come up with the internal structure by inference. Researcher's comment: Student was able to raise the concept of producing scientific knowledge by inference, but he failed to explain how the knowledge is produced by inference.
Informed views	2563* Post-test: I believed the model. Since the scientific knowledge produced by a series of experiments, from which , knowledge is inferred. Scientists did the detection of geology, by the series of sonic detection to produce the model of the internal structure of the earth, so it has a higher degree of reliability. Researcher's comment: The student knew the process of scientific knowledge development was based on a series of experiments and knowledge was inferred from the findings.

** the student's identification number in questionnaire*

Table 20 Examples showing how students' responses regarding the theory & law tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Distinction between theory and laws - Theories and laws are the scientific knowledge, but they are different in meaning. Scientific laws are reports or explanations of the relationships among observation; scientific theories are inferred explanations for observation. VNOS-D+ Q8 "*Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.*"
Naïve views	1535* Post-test: They had no difference. Since they were science too. Researcher's comment: Student did not know the definition of theory and law, so he treated them as the same and could not provide any examples to explain.
Mixed views	1532* Post-test: They were different. Law describes the relationship between the observable phenomena. Theory is to explain the observable phenomenon. Researcher's comment: Student was able to identify the definition of the law and theory clearly, but he failed to provide examples to explain the answer.
Informed views	2657* Post-test: Scientific law describes the relationship between observable phenomena. For example, sound transmission is faster in water than air. This is the law, which just describes the phenomenon. Theory explains the phenomenon. For example, the molecular densities were different in water and air, which causes the difference in sound transmission. Researcher's comment: Student was able to describe the definition of the scientific law and scientific theory, and he was able to use the example of sound transmission difference in different media as an example to illustrate the difference between the two.

** the student's identification number in questionnaire*

Table 21 Examples showing how students' responses regarding the creativity & imagination tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Creativity and imagination - Creativity and imagination are involved in the production of scientific knowledge. VNOS-D+ Q7 "*Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?"*
Naïve views	1623* Pre-test: I don't think so. Since the scientific knowledge could not be produced by imagination. It must have very concrete evidence to support. Researcher's comment: The student rejected imagination and creativity as components of the nature of science, which were involved in scientific knowledge development.
Mixed views	2561* Pre-test: Yes, it includes imagination and creativity to discover new things by experiment, to realize and understand new things. Researcher's comment: Student expressed that imagination and creativity were involved in the production of scientific knowledge, but he failed to provide examples to explain his answer.
Informed views	2560* Post-test: Yes. imagination and creativity were involved in the planning of experiment. New knowledge could be discovered by scientific investigation. For example, for the appearance of dinosaur, people used fossil records to predict and demonstrate the rough appearance. But for the more detailed parts, they would use imagination to figure out. Researcher's comment: Student knew imagination and creativity were the part of scientific knowledge production. He could use the example from the questionnaire to explain the appearance of dinosaur. Scientists not only used the information from fossil record, but also used their own imagination.

** the student's identification number in questionnaire*

Table 22 Examples showing how students' responses regarding the tentativeness tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Tentativeness - Scientific knowledge is tentative, and the knowledge is subject to change when new evidence is discovered by an advanced technology, leading to new theory to interpret the existing knowledge. VNOS-D+ Q3 *"Scientists created scientific knowledge. Do you think that scientific knowledge may be changed in the future? Explain your answer with example."*
Naïve views	1526* Pre-test: It can make our lives more convenient. It is also hazardous to our environment. More and more animals would become extinct or their populations would decrease due to the pollutants produced by human beings. For example, the population of polar bear would decrease due to global warming. As human beings keep this development going, the environment of the earth may be changed, which may affect the food chain. Researcher's comments: This student did not respond to the question to express whether the scientific knowledge would change or not in the future. He was just describing the effect of environmental changes on organisms on the earth.
Mixed views	1527* Pre-test: Yes, it is because as the world is changing, many things would change as well. The same happens to our society, where there are many high technologies having been invented. 1541* Pre-test: Yes. Science is embedded in our lives. Based on the scientific knowledge developed, we would realize more about our surroundings. So our future would be changed, and many new things would be invented. 2560* Post-test: Yes, scientific knowledge would be changed. Since there are incurable disease to be curable. Researcher's comments: These students just expressed their beliefs that scientific knowledge would be changed in the future, but they were unable to provide concrete example to support or describe why they believed it.
Informed views	2561* Post-test: It is changeable, since scientific knowledge is tentative and changeable. For example, the doctor said that there were bacteria inside the stomach that cause stomach disease. But it was banned by others, since there is gastric juice, which is acidic, and all the bacteria would be killed by that time. But it was discovered that there are bacteria causing disease by experiment. 2645* Pre-test: It is possible for change in scientific knowledge, since our existing scientific knowledge development may be hindered by existing

	scientific technology, causing the inaccurate result to be produced. In the future, the existing scientific knowledge may be rewritten by new standard of technology. For example, it was believed that the earth was flat in the past, but it was replaced by observation and experiment due to technology advancement, such as ship, compass and map. Researcher's comments: These students were able to provide their views on the tentativeness of scientific knowledge. They could also provide evidence and examples to support their views.

** the student's identification number in questionnaire*

Table 23 Examples showing how students' responses regarding the subjectivity tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Subjectivity - Scientific knowledge is subjective, which is affected by the human's prior knowledge in science. VNOS-D+ Q4c "*Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what caused this to happen. Why do you think they disagree even though they all have the same information.*"
Naïve views	1532* Pre-test: There were different dinosaurs that died at different times. Researcher's comment: Student could not directly point out although the same data was obtained by scientists, scientists might apply different reasoning to explain the extinction of dinosaurs. He just repeated the question without contributing any new ideas.
Mixed views	1617* Post-test: It is because different people have different thinking methods. Researcher's comment: The student could point out the concept of subjectivity, but he failed to explain how such subjectivity affects the emergence of different opinions.
Informed views	2565* Post-test: Scientific knowledge is subjective. Every scientist has their thinking methods and past experiences. Therefore, the ideas should have come from different ways of thinking.

** the student's identification number in questionnaire*

Table 24 Examples showing how students' responses regarding the social & cultural embeddedness tenet of NOS were categorized according to the rubric for VNOS-D+

NOS tenets	Social and cultural embeddedness - Scientific knowledge is interactive with both society and culture. VNOS-D+ Q10 "*Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide examples.*"
Naïve views	1612* Pre-test: No relationship. Science had no relationship with society and culture. Researcher's comment: The student rejected the tenet of NOS, which suggests that social and cultural factors are involved in the development of scientific knowledge.
Mixed views	1535* Post-test: Yes, they had relationship. It is because science influenced people by changing their value. Researcher's comment: The student accepted the concept of social and cultural factors in influencing the development of scientific knowledge, but he failed to explain with examples.
Informed views	2561* Post-test: Referring to the outbreak of bird flu, the government need to do more researches and experiments to discover the vaccine to cure the patients and stop the spread of disease. They also need to find out the source of the outbreak and control the disease. Researcher's comment: The student was able to corelate the vaccine development with the outbreak of the disease in the community.

** the student's identification number in questionnaire*

To facilitate statistical analysis, the scoring rubric of "informed", "mixed" and "naive" were converted into numerical scores as follows: -

"2" for informed view,

"1" for mixed view and

"0" for naïve view.

For the quantitative analysis, the paired *t*-test was conducted to analyze the difference or gain in the students' performance from the pre-test to the post-test. Pearson's correlation was used to analyze the relationship among seven tenets of NOS for each of the two teaching approaches. Any possible correlational relationship between the seven tenets of NOS and the students' general biology achievement was also analyzed using Pearson's correlation. ANCOVA was employed to analyze the difference between the two teaching approaches in learning the seven tenets of NOS. A special type of ANCOVA, the two-way ANCOVA, was used to analyze the interaction between gender and students' biology academic performance, and the two teaching approaches in affecting the students' learning of NOS. The students' written responses to individual items of the VNOS-D+ post-test questionnaire were subject to more in-depth qualitative analysis to identify the nuanced differences in the students' understanding of the seven NOS tenets between the two teaching approaches. These findings were considered together with the data collected from the lesson observations and semi-structured interviews, which were used to triangulate the findings of the quantitative statistical analysis.

The following sections report the findings of the quantitative and qualitative analyses with reference to the each of the three research questions for this study.

4.2 RQ1: Could the SSI and HOS teaching approaches enhance Hong Kong senior secondary students' understanding of major tenets of NOS?

The first research question is "Could the SSI and HOS teaching approach enhance Hong Kong senior secondary students' understanding of the major tenets of NOS?" Since there were many researches reporting that the SSI teaching method was able to enhance the students' learning using socio-scientific issues as a context to motivate students to explain and appreciate the social and cultural tenet of NOS (Eastwood et al., 2012; Schalk, 2012). That is to say, science is subject to the influences of societal and cultural factors, which might either encourage or discourage scientists to pursue their research in a certain direction. However, all of these research evidences were obtained from contexts outside Hong Kong. It has left one wondering whether the SSI approach is equally effective in improving Hong Kong Senior secondary biology students in learning NOS, compared with the HOS approach that is commonly adopted in Hong Kong. This research question was addressed by subjecting the quantitative data obtained from the VNOS-D+ questionnaire to statistical analysis. The paired *t*-test was used to check the effectiveness of the SSI teaching method in enhancing students' understanding of NOS before and after the intervention to see whether there were any significant differences. Table 25 showed the result of the statistical analysis using the paired *t*-test for the SSI teaching approach from the pre-test to the post-test. The results show that the post-test score for all the seven tenets of NOS was higher than the pre-test score, and the results were statistically significant. This shows that the SSI approach was effective in enhancing students' understanding of NOS. Table 26 shows the improvement in the students' understanding of the seven NOS tenets from pre-test through to the post-test using the SSI approach.

Table 25 Descriptive statistics for the SSI group from pre-test to post-test.

Pair	NOS tenets	Pre-test			Post-test		
		Mean	SD	SE Mean	Mean	SD	SE Mean
1	Empirical basis	0.438	0.496	0.101	0.771	0.531	0.108
2	Observation & inference	0.267	0.122	0.025	0.751	0.426	0.087
3	Theory & Law	0.460	0.509	0.104	0.880	0.797	0.163
4	Creativity & Imagination	0.500	0.511	0.104	1.104	0.659	0.135
5	Tentativeness	0.896	0.390	0.080	1.181	0.479	0.098
6	Subjectivity	0.125	0.221	0.045	0.540	0.509	0.104
7	Social & Cultural embedded	0.710	0.550	0.104	1.210	0.509	0.104

Table 25 shows that for all the seven NOS tenets except *tentativeness* and *social & cultural embedded*, the mean score achieved by the students are lower or equal to 0.5, implying a relatively low degree of understanding among the students of the SSI group before the intervention. The mean pre-test score for all the seven tenets was calculated to be 0.485. However, after the intervention, the mean score for the seven tenets went up to 0.919, showing a 43.4 percentage increase. All of the seven tenets except for *subjectivity* increased to 0.751 or above. *Subjectivity* recorded the lowest score in the post-test, implying that the students' understanding of this NOS tenet was still rather poor despite the intervention. On the other end, the score for *tentativeness* remained the highest from the pre-test through to the post-test. This implies that this tenet seemed to be easier for the students to understand compared with other tenets.

An effect size is a way to give the measure of the practical significance of the result findings. The way to calculate the effect size for a paired *t*-test, the mean difference is divided by the standard deviation of the difference (Cohen, 1988). The value of the Cohen's d is as follows:

Strength	Effect size
Small	0.2
Medium	0.5
Large	0.8

Table 26 Results of Paired t-test for the SSI group from pre-test to post-test.

Pair	Tenets of NOS	Mean	SD	SE Mean	Lower	Upper	*t*	Df	Sig. (2-tailed)	Effect Size
1	Empirical basis	-0.333	0.64	0.13	-0.602	-0.064	-2.563	23	0.017	0.52
2	Observation & inference	-0.484	0.35	0.07	-0.631	-0.338	-6.856	23	0.000	1.38
3	Theory & Law	-0.417	0.72	0.15	-0.720	-0.114	-2.846	23	0.009	0.58
4	Creativity & Imagination	-0.604	0.68	0.14	-0.889	-0.319	-4.383	23	0.000	0.89
5	Tentativeness	-0.285	0.52	0.11	-0.504	-0.066	-2.688	23	0.013	0.55
6	Subjectivity	-0.417	0.57	0.12	-0.655	-0.178	-3.615	23	0.001	0.73
7	Social & Cultural embedded	-0.500	0.78	0.16	-0.829	-0.171	-3.140	23	0.005	0.64

Table 26 shows the mean difference between the pre-test and the post-test for the seven tenets, with all differences being statistically significant ($p<0.05$). A greater difference, which means greater improvement in those tenets, was observed for *creativity & imagination* and *social & cultural embedded*. This implies that the students could learn better in these tenets from the teaching of SSI. And the least improvement was tenets of *empirical basis* and *tentativeness*. The least improvement was shown in *tentativeness.* This could be due to the ceiling effect, that is, students had achieved a rather high score in the pre-test, leaving little room for further improvement. There were five tenets with a medium effect and the effect size was greater than

0.5, which were the tenets of *empirical basis*, *theory & law*, *tentativeness*, *subjectivity* and *social & cultural embedded*. The two tenets with a relatively high effect size, both greater than 0.8, were *observation & inference* and *creativity & imagination*.

Overall, the results show that the SSI teaching approach was able to improve Hong Kong students learning of all the seven tenets of NOS, and the improvement was statistically significant.

For the existing teaching approach – HOS, what was the students' performance after teaching with HOS compared with before? Table 27 showed the result of the pre-test score and post-test score for the HOS treatment group (or the control group).

Table 27 Descriptive statistics for the HOS group from pre-test to post-test.

Pair	NOS tenets	Pre-test		Post-test	
		Mean	SD	Mean	SD
1	Empirical basis	0.41	0.507	0.85	0.493
2	Observation & inference	0.29	0.119	0.84	0.345
3	Theory & Law	0.47	0.514	0.82	0.809
4	Creativity & Imagination	0.59	0.507	1.21	0.639
5	Tentativeness	0.97	0.329	1.24	0.449
6	Subjectivity	0.15	0.235	0.53	0.514
7	Social & Cultural embedded	0.65	0.493	1.24	0.437

Table 27 shows that for all the seven NOS tenets except *creativity & imagination*, *tentativeness* and *social & cultural embedded*, the mean pre-test score achieved by the students were lower or equal to 0.5, implying a relatively low degree of understanding among the students of the HOS group before the intervention. The mean pre-test score for all the seven tenets was calculated to be 0.50. However, after the intervention, the mean score for the seven tenets went up to 0.96, showing a 46.0 percent increase. The percentage of improvement in HOS was similar to that for SSI. All of the seven tenets except for *subjectivity* increased to 0.82 or above. Similar to the SSI teaching approach, *subjectivity* recorded the lowest score in the post-test, implying that the students' understanding of this NOS tenet was still rather poor despite the intervention. On the other end, the score for *tentativeness* remained the highest from the pre-test through to the post-test. This implies that this tenet seems to be easier for the students to understand compared with other tenets.

Table 28 Results of the paired t-test for the HOS group from pre-test to post-test

Pair	Tenets of NOS	Mean	SD	*t*	df	Sig. (2 tailed)	Effect Size
1	Empirical basis	-0.441	0.659	-2.762	16	0.014	0.67
2	Observation & inference	-0.544	0.257	-8.725	16	0.000	2.12
3	Theory & Law	-0.353	0.493	-2.954	16	0.009	0.72
4	Creativity & Imagination	-0.618	0.740	-3.441	16	0.003	0.84
5	Tentativeness	-0.265	0.483	-2.262	16	0.038	0.55
6	Subjectivity	-0.382	0.600	-2.626	16	0.018	0.64
7	Social & Cultural embedded	-0.588	0.712	-3.405	16	0.004	0.83

Table 28 shows the mean difference between the pre-test and post-test. From the findings, *creativity & imagination* and *social & cultural embedded* showed a greater difference than the others, implying greater improvement than the other tenets after the intervention by the HOS approach. The findings were same as that of the SSI teaching approach. This implies that the students could learn equally well using either one of the two teaching approaches with respect to those two tenets. And the least improvement was shown by the tenet of *tentativeness*. Again, as in the case of SSI group, this might be explained by the ceiling effect as the mean pre-test score for this tenet was also the highest among all the tenets. There were four tenets with an effect size greater than 0.5, which were tenets of *empirical basis*, *theory & law*, *tentativeness*, and *subjectivity*. An effect size greater than 0.8 was observed in the tenets of *observation & inference, social & cultural embedded* and *creativity & imagination*.

Thus, according to the results of the paired *t*-test analysis, the HOS teaching approach was able to improve students' understanding of all the seven tenets of NOS with statistical significance.

In summary, students displayed statistically significant improvement in all the seven tenets after learning through the SSI and HOS approach from the pre-test through to the post-test. This implies that both approaches were able to improve students' understanding of NOS, and could be considered as effective as far as promoting NOS education is concerned.

It would be interesting to investigate whether there was any association among all the seven tenets with respect to students' learning of these tenets. This may yield further insights into whether students understanding of these tenets are independent of each other or not. This was done by running a Pearson's correlation. Table 29 shows the result of Pearson's correlation between the gain in score for the seven NOS tenets from the pre-test to the post-test for the SSI treatment group.

Table 29 The Pearson's correlation of score gain between the seven NOS tenets for the SSI group

NOS	Empirical	Observation	Theory	Creativity	Tentativeness	Subjectivity	The Social
Empirical	1	0.280	-0.317	-0.135	-0.069	0.292	0.350
Observation		1	0.167	0.091	0.297	0.506*	0.182
Theory			1	-0.004	-0.021	0.197	0.000
Creativity				1	-0.223	0.109	-0.103
Tentativeness					1	0.097	-0.063
Subjectivity						1	0.148
The Social							1

*Correlation is significant at the 0.05 level (2-tailed).

The results show that there was a strong positive correlation between the gain in score for *observation & inference* and *subjectivity*, r = .506. This means that when students had greater improvement in the *observation & inference* tenet, they would also show greater improvement in the *subjectivity* tenet.

Likewise, Pearson's correlational analysis was used to test if there are similar correlations for the HOS treatment group. A comparison between the two treatment groups in this aspect is particularly worthwhile as this could provide more insights into the differences between the impact of the SSI and HOS teaching approach. Table 30 displayed the Pearson's correlation between the seven tenets for the HOS treatment group with respect to the gain in score.

Table 30 The Pearson's correlation between the seven tenets of NOS for the HOS group

NOS	Empirical	Observation	Theory	Creativity	Tentativeness	Subjectivity	Social
Empirical basis	1	0.302	-0.317	-0.145	-0.259	0.258	0.145
Observation & inference		1	0.124	-0.021	-0.069	0.512*	0.572*
Theory & law			1	-0.121	-0.023	0.149	0.262
Creativity & imagination				1	-0.341	0.068	-0.139
Tentativeness					1	-0.155	0.004
Subjectivity						1	0.099
Social & cultural embedded							1

**Correlation is significant at the 0.05 level (2-tailed).*

As shown in Table 30, there was a strongly positive correlation between the gain in score for *observation & inference* and the gain for *subjectivity* (r = .512) and between the gain for *observation & inference* and the gain for *social & cultural embedded* (r = .572). This means that when students showed greater gain in the *observation & inference* tenet, they would also exhibit greater gain in the *social & cultural embedded* tenet. By the same token, for students that showed greater gain in the *observation & inference* tenet, they would also show greater gain in the *social & cultural embedded* tenet.

4.3 RQ2: Which approaches, the SSI approach or HOS approach, could help Senior Secondary Biology students developing more informed conceptions of the major NOS tenets?

The second research question for this study inquired into the relative effectiveness of the two different teaching approaches in improving student understanding of the various tenets of NOS. According to the descriptive statistics, it was found that the overall mean score of the posttest was higher than the overall mean score of the pretest for two groups of students to a statistically significant extent. It could thus be concluded that both the HOS and SSI approach were able to improve the students' understanding of all tenets of NOS to comparable degrees after the intervention. Such improvement in understanding is likely to imply that both approaches were effective in enhancing student learning of NOS. Moreover, it was found that all students got very low score in all the seven tenets of NOS in the pretest, implying that the students' concepts of NOS were weak or ineffective. This might imply that the science curriculum of the junior forms was not as effective as expected in promoting students' understanding of NOS. The possible underlying causes would be discussed in the next chapter.

Despite the finding that both approaches were able to improve students learning of NOS, the finding from the ANCOVA showed that there was no statistically significant difference between the two teaching approaches in students' gain in understanding across all the seven tenets of NOS. Thus, it is not possible to conclude which of the two approaches was more effective in learning NOS and, hence, enhancing students' understanding of the NOS tenets.

Table 31 below shows the Univariate Test Statistics on the two teaching approaches with respect to the seven tenets of NOS using ANCOVA (with the pretest score as the covariate).

Table 31 Univariate Test Statistics for the two teaching approaches on various tenets of NOS by ANCOVA (pretest as covariate)

Tenet of NOS	Approach	Posttest Mean	Posttest SD	Univariate Test Statistic	η^2
1 Empirical basis	HOS	0.853	0.493	F(1,38)=0.825, p=0.369	0.021
	SSI	1.042	0.706		
2 Observation & inference	HOS	0.835	0.345	F(1,38)=0.381, p=0.541	0.010
	SSI	0.757	0.425		
3 Theories & Laws	HOS	0.820	0.809	F(1,38)=3.323,p=0.076	0.080
	SSI	1.130	0.850		
4 Creativity & imagination	HOS	1.206	0.639	F(1,38)=0.537, p=0.468	0.014
	SSI	1.063	0.742		
5 Tentativeness	HOS	1.235	0.449	F(1,38)=0.675, p=0.416	0.017
	SSI	1.056	0.465		
6 Subjectivity	HOS	0.530	0.514	F(1,38)=0.619, p=0.436	0.016
	SSI	0.670	0.637		
7 Society & cultural embeddedness	HOS	1.240	0.437	F(1,38)=2.431, p=0.127	0.060
	SSI	1.500	0.590		

4.4 Qualitative analysis of students' response to VNOS-D+ questionnaire in the post-test

For both teaching approaches, the students displayed significant increase from the pre-test to post-test score for each NOS tenet. However, when the two teaching approaches were compared by ANCOVA, no statistically significant difference between the two was found. To yield further information that could lead to deeper insights into the nuanced differences, if any, between the two approaches, all the student post-test questionnaires were analyzed qualitatively. The student's responses to individual NOS items in the post-test questionnaire were subject to qualitative analysis through a three-step process. This process involves theme categorization, coding and interpretation. The completed post-test questionnaire for students in both groups was read thoroughly to identify recurrent themes. These themes include concepts or misconceptions that occurred rather frequently for individual tenets. All the themes identified were presented in table form with the support of relevant utterances or statements extracted from the responses.

Tables 32 - 37 showed the different themes generated from the responses as students recorded in their post-test questionnaires. A total of six themes were identified from the post-test questionnaire. These six themes are: "knowing is seeing", "believing authority's claim", "believing technology / machine", "incomplete understanding of the role of subjectivity", "using examples from previous learning" and "using examples from the intervention process".

Table 32 Qualitative analysis of students' responses to NOS on theme of knowing is seeing (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*	Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*
10/17 (58.8%)	1527(4b): Not really sure the appearance of dinosaur. Since the scientists only used the fossil record to infer the structure of dinosaur, no one has seen the real dinosaur before. And, no one has seen the internal structure of the earth; they just infer the structure only. 1530(Q6): No. Since the internal structure of the earth was simulated by computer, no one has seen the	7/24 (29.2%)	2571(4b): 50% believing the appearance of dinosaur. Since there were no one has seen the real dinosaur before. 2560(4b): not really believing the appearance of dinosaur, since I have never seen it, the appearance was produced by computer animation only. (Q6): Not accurate. Since no one has seen the internal structure of the earth, they just used the machine

	structure, so the result is not reliable. 1532(4b): mostly believing the appearance of dinosaur, since the appearance was produced by inference and subjectivity, since no one has seen the real appearance of the dinosaur. (Q6): Not sure, since no one has been inside of the earth, people used their inference and imagination to produce the earth model. 1534(4b): It only used the fossil record to deduce the dinosaur, it may be changed in later. Since no one has seen the dinosaur before. 1535(Q6): not sure. Since no one has been there. 1537(4b): I'm not sure the appearance of dinosaur, since there were no people have seen it before, or no diagram or photo to prove the presence of dinosaur. It is guessed by scientists. 1612(Q6): Not sure, since our technology cannot allow people get into the deep of earth to explore, we just predict the structure only. 1617(4b): I'm not sure the appearance of dinosaur, since the appearance was imagined, no people have seen its appearance. 1622(4b): 60-70% believing the appearance of dinosaur, since scientists used the fossil record to infer the structure of dinosaur, but they have not seen their real appearances. 1530(4b): Not really believing, since the appearance was inferred, no real appearance for us to see.		to measure, then made the model by imagination. 2569(Q6): not accurate. Since it was imagined by scientist as a reference model, and no one has seen it. 2644(Q6): not precise, since there no one has seen the internal structure of the earth. It was inferred by subjectivity. 2649(Q6): Disagree with the internal structure of the earth model, since no people have got into the inside of the earth to see the structure. 2653(Q6): No. it is based on their inference and creativity and imagination. You cannot cut the earth into half to see what is in the earth. 2657(Q6): Cannot. Since scientists used their imagination, no one has been inside of the earth, it is produced by imagination, so it may not sure.

Theme 1: Knowing is seeing

There were more than half of the students from the HOS group in Table 32, who expressed that they only believed in scientific knowledge by actually seeing. For instance, those students claimed that they would not believe the appearance of dinosaur and the internal structure of the earth for the reason that they had not seen them before. This strongly indicates that they believed in scientific knowledge only by seeing. There were 10 students out of 17 from HOS group (58.8%) replied not believing without actually seeing in their post-test questionnaire with regard to the appearance of dinosaur and the structure of the earth. 7 students out of 24 from SSI group (29.2%) showed the same belief as those in the HOS group. This student belief could be taken further to imply that those students failed to appreciate that *imagination and creativity* are needed to come up with feasible scientific claims, for instance, about the appearance of dinosaur and its structure, as well as about the internal structure of the earth. That is to say, those students failed to perceive imagination and creativity as important components of the nature of science. This theme was further discussed when reporting the findings of the semi-structure interview.

Table 33 Qualitative analysis of students' responses to NOS on the theme of believing authority's claim (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire..*	Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire..*
1/17 (5.9%)	1536 (Q6): I believed since it is claimed by scientists, I don't know anything about it. It seems no other claims to reject this model.	1/24 (4.2%)	2563(Q6): I believe that it is accurate, since scientific knowledge was produced by a series of experiments. Scientists used the ultrasound detection to perform a series of experiments, then the earth model was produced. So, I tend to believe the model.

Theme 2: Believing in authority's claim

In Table 33, there were a few students believing in authority's claim in the HOS treatment group, with 5.9% and in the SSI treatment group with 4.2%. Those students tended to believe that scientists have better knowledge than they have, so they switched to believe scientists' claims as authoritative ones, without necessarily the support of evidence. This theme seems to oppose the tenet of subjectivity, as mentioned before, the subjective knowledge can become less subjective through the exercising of reasonable skepticism with the support of empirical in the process of ongoing inquiries. This can be an area for further exploration into the students' poor performance in their understanding of subjectivity using both the HOS and SSI approaches as shown by the quantitative findings.

Table 34 Qualitative analysis of students' responses to NOS on the theme of believing technology / machine (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire..*	Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*
5/17 (29.4%)	1541(Q3): Yes, science was to a certain extent related to society and culture. With technological development, we could reason more deeply, as we received new data, reject the experimental result, or improve the scientific laws in the past, such as heliocentric, which was rejected when the time goes. 1542(Q3): Will be. Scientific development was affected by the current technology and facility. They will change when the time goes. Their answers will be completed or rejected, such as discovery of cell. 1612(Q3): Yes. Machine will be updated and can cure disease. 1617(Q6): Yes. Since it used machine to detect for many times, then more accurate results will allow better inference about the structure. 1622(Q3): Yes, it will change. Because the technology may be advanced in future, new research result will come out. Science is tentative and limited by the current scientific level.	1/24 (4.2%)	2560(Q6): Not sure. Since no one has seen the internal structure of the earth, we used the machine to measure and imagine the structure.

<u>*Theme 3: Believing technology / machine*</u>

Moreover, there were a few students who displayed the theme - believing technology / machine as shown in Table 34. This theme seemed to be more common among students in the HOS group (with 29.4%) than their counterparts in the SSI group (with 4.2%). These students tended to think that machine was powerful and could do anything. From this theme, one may infer that the role of technology in the development of science is more noticeable when viewing from a historical perspective. This may also provide a clue for explaining the better performance of the students in the HOS group than those in the SSI group with respect to their understanding of the tenet of tentativeness, which recorded the highest score in the post-test among other tenets.

Table 35 Qualitative analysis of students' responses to NOS on the theme of incomplete understanding of the role of subjectivity (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*	Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*
4/17 (23.5%)	1530 (4c): Because people only see their own inference and conclusion based on different cultural values. 1532 (4c): Because it is subjective. Reasonable doubt can cause improvement of science. 1542 (4c): Since science always carries subjectivity. Although the data gain are different, they use their data to make different deduction. 1613 (4c): Because science must use subjectivity, and make assumptions on the reason of extinction.	9/24 (37.5%)	2561 (4c): Because scientific knowledge is subjective. Although they gained the same information, their points of view, imagination, creativity and inference were different. 2563 (4c): Since scientific knowledge is subjective. Scientist have their own thinking and standpoint. For events happening a very long time ago, no one know the real answer. Therefore, there are rooms for imagination and assumption, Scientists have their own points and their ideas are different. 2565 (4c): Scientific knowledge is subjective. Every scientists have their way of deduction and their own experience. Thus having different ideas is normal. 2573 (4c): Although they had the same information, since science was subjective, they can have different thinking method and answer. 2574 (4c): Because science is subjective, different people having different points of views is normal.

			2648 (4c): Science is subjective. Every people have their own deduction and imagination, so they will come up with different reasons for extinction. 2651(4c): Because they were based on observation and deduction. The different ideas were due to their own personal feelings. 2654 (4c): Because science is subjective. Every scientist has their own thinking, so different ideas appear. 2658(4c): Since science is subjective, every scientist has different field of study and different point of views.

Theme 4: Incomplete understanding of the role of subjectivity in science

For the theme – Incomplete understanding of the role of subjectivity in science in Table 35, it was noted that some students had developed only partial understanding of the idea of subjectivity. Although they knew what subjectivity means in the context of science knowledge development, they tended to perceive scientific knowledge having a subjective element rather than relating subjectivity to the science inquiry process or practice. There were 23.5% of students from the HOS group that showed this idea compared with 37.5% of students from the SSI group expressing similar conception. Such as *2654 (4c): Because science is subjective. Every scientists had their own thinking, so different ideas appear*. The above student thought that scientific knowledge is subjective as a result of scientists' different perspectives on understanding certain natural phenomena. With this view of subjectivity in mind, students might treat this tenet as a limitation to the development of science. However this is not quite true. Subjectivity should be more appropriately regarded as a starting point for scientific inquiry. The purpose of such inquiry is to search for more objective evidence to validate or refute any subjective idea or hypotheses, ending up with consensus building within the scientific community. Although scientists may start with contradictory hypothesis or research methods that they subjectively chose, if they are able to collect evidence in a systematic and logical manner, they should come to similar conclusions, leading to the construction of more objective knowledge.

Table 36 Qualitative analysis of students' responses to NOS on the theme of using examples from intervention (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*	Number (%) of students reflecti ng this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*
5/17 (29.4%)	1528(Q8): Scientific law is not changed; it describes the relationship between observable phenomenon. Theory, just to enrich the law by explaining the relationship. Example of law is Mendel's first law. Example of theory is theory of evolution. 1541(Q8): Law just describes the relationship between observable phenomena. Theory just explains the phenomenon. For example, Mendel's second law describes the relationship between phenomenon. Theory of evolution and cell theory explain the phenomenon. 1611(Q3): Yes. It will. Scientific knowledge is tentative and subject to be changed, such as the invention of vaccine. 1612(Q7): Yes. In the case of cowpox, it was not supposed to think the smallpox was able to be prevented. It must involve imagination and creativity. 1617(Q3): Yes, since scientific knowledge is tentative and subject to be changed, such as the discovery of bacteria inside stomach.	9/24 (37.5%)	2560(Q10): There are relationships. Since scientists will change according to the demand. During SARS, all scientists spent their efforts on the research of SARS. 2561(Q10): During the outbreak of bird flu, the government needed to do more research and experiment on the production of vaccine to stop the spread of the disease. 2563(Q10): Yes. There are mutual influences. Scientific knowledge may be influenced by the society and culture. For example, when there was a disease outbreak, scientists will spend their time on the research of that disease. 2564(Q10): Yes, for example in the outbreak of SARS, many scientists spent their effort on the research to stop the spread of disease. Then with the outbreak of bird flu, scientists also spent their effects on it too. 2565(Q10): They are related. For example, in the outbreak of SARS at 10 years before, scientists spent their time on the research of how to stop and producing vaccine. 2569(Q10): Yes. Take medical field as an example, doctors will take epidemiology as the research target. In

			the outbreak of flu, doctors will do more researches on it. 2648(Q7): Yes. Planning experiments requires imagination and creativity since it is needed to think about what the reason will be, then producing the experiment to prove that. For example, scientists suspected water caused the breeding of mosquitoes, so they did experiment to prove that. (Q8): Different, law just claims that the number of mosquitoes increased due to water. Theory would explain that water is the medium of mosquitoes to lay eggs, so the number of mosquitoes increased. 2654(Q7): Yes, they used creativity and imagination in the research work. For example, during SARS, people thought that SARS disease was spread by eating wild animals. But someone guessed it might come from bat, finally it was proved. 2657(Q10): Yes, scientific research is related to the existing society. For example, in SARS, people suffered more seriously in society, then scientists did a lot of researches on how to produce a vaccine for this disease.

Theme 5: Using examples from the intervention

As shown in Table 36, a higher percentage of students in the SSI group exhibiting the theme - using examples from the intervention - compared with the HOS group. 37.5% of the students in the SSI group (with 9 out of 24) used examples abstracted from the intervention process in their responses to the VNOS-D+ questionnaire items, eight students out of a total of nine used disease outbreak as an example to explain their choices in the questionnaire; and one student out of nine used mosquito breeding as an example to explain his choice. It might be due to the fact that the students had become more familiar with disease outbreak after going through the intervention process. For the HOS group, there were five students' responses out of 17 that made use of examples drawn from the intervention to support their claim. Two out of five used Mendel's law; two students out of five used the discovery of vaccine; and one out of five students used the discovery of bacteria inside the stomach to support their claim.

Table 37 Qualitative analysis of students' responses to NOS on the theme of using examples from previous learning (Post-test Questionnaire)

HOS group		SSI group	
Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*	Number (%) of students reflecting this theme	Examples of utterances/instance *[The number (e.g.1527) refers to the student identity, and the number with an English letter (e.g. 4b) refers to the question number in the questionnaire.*
6/17 (35.3%)	1527(Q8): Law: describes the relationship between observable phenomena. Theory explains the phenomenon. For example, theory is theory of evolution; law is Newton's law. 1537(Q7): Yes, they planned to perform experiment with creativity and imagination. For example, the earth is not spherical, and less malaria was found in the area of Africa. 1541(Q3): Yes. Science always have a certain degree of correlation with society and culture. As technology developed, people can realize more about their living environment or phenomenon. When they got new data from experiment, the previous knowledge may be rejected or improved. For example, heliocentric had taken a long time to be proved. (Q7): Yes. In planning an experiment, creativity is needed. During data analysis, data interpretation and reporting result also needed creativity and imagination. For example, creativity is needed to discover the cell model, . 1542(Q7): Yes. Their planning, data analysis, data interpretation, and	17/24 (70.8%)	2559(Q8): Science theory is theory of evolution. Science law is law of gravity. 2561(Q3): It will be changed in future. Since scientific knowledge is tentative. For example, a doctor said that there were bacteria inside the stomach causing gastric ulcer, it was laughed at by other doctors, since they supposed to gastric acid could kill bacteria. Then the doctor did experiment to prove that there were bacteria surviving in the stomach and causing gastric ulcer. 2563(Q3): I think it will be changed in future. People believed that heavy material dropped faster than lighter one. But it was rejected after several years by the experimental finding that only shape and volume would affect the speed of falling. (Q7): Yes, scientific knowledge is needed to make inference, with the use imagination and creativity. For example, Newton was hit by an apple dropped from a tree. Then he thought that there was the gravity underground to cause the apple dropping from the tree. So, he used his imagination to make a hypothesis, and did the experiment to prove his hypothesis. 2564(Q3): Yes, science is subjective. For example, some one thought that

	modeling required imagination and creativity, such as cell modeling. 1613(Q3): Yes. Using DNA parental matching to prove the relationship. 1617(Q7): Yes. Planning, interpretation and performing experiment and observation. For example, for the observation of dropping apple, it was hypothesized there was a force to attract apple to the ground. (Q10): Yes. Scientific knowledge always has a relationship with the society and culture. If there is a need in society, scientists will start their research on it. For example, embryonic DNA test was conducted to get rid of inheritance diseases.		the earth was flat, and some one thought that the earth was spherical. 2565(Q3): Yes. The scientific knowledge is tentative and subject to change. For example, people thought that the earth was flat, but finally it was proved that the earth was spherical. 2569(Q3): Yes. For example, in Darwin's theory of evolution, it is claimed that the single cell is the origin to start the development into different organisms. Then other scientists kept using this concept to further develop this theory. (Q7): Yes, people suggested the shape of the earth was supposed to be spherical and not flat, then he did the experiment to prove his hypothesis. He sailed around the earth to prove his claim, finally he proved that the shape of the earth was spherical. 2644(Q3): in the future, many vaccines will be produced to stop the disease. Cloning technology will be used to reproduce human for replacing failed organs by organ transplantation. So scientific knowledge can solve the problem. 2645(Q3): Yes, technology would be updated. For example, the shape of the earth was believed to be flat, but it was rejected due to technological advancement. People then knew the shape of the earth was spherical. 2648(Q3): Yes. Scientific knowledge was tentative and subject to change. In the past, the incurable disease H5N1 could be cured now. 2649(Q3): Yes. The development of light bulb has changed our life. 2650(Q3): Yes. Because that knowledge is tentative and it all can be changed. For example, in the 19th-20th century, people died of smallpox, but now we can prevent smallpox. 2652(Q3): Yes. Scientific knowledge is tentative and subject to change. For example, the theory of evolution has changed for several years by new observation and inference.

			2653(Q3): Yes. Scientific knowledge is tentative and subject to change. For example, people thought that the earth is square shape, however, after sometimes people find out that the earth is oval shape. (Q8): Law describes the observable phenomenon such as, Mendel's second law. Theory explains the observable phenomenon, such as the theory of evolution. 2654(Q3): Scientific knowledge will change in future. Science is tentative and subject to change. For example, gastric ulcer was not caused by excessive gastric acid production but by the bacteria inside. 2655(Q3): Yes. Because scientific knowledge is tentative due to the improvement on technology. For example, considering the discovery of cell, people don't know some typical cell before but after some improvements on technology, they discover new cells. (Q8): Law describes the relationship between observable phenomena, while theory explains the relationship between observable phenomena. for example, the law of segregation, and theory of evolution. 2657(Q3): Yes, it will change. Since scientific knowledge is tentative, and it is subject to change according to the advancement of technology. For example, people thought that the shape of the earth was flat, but it was rejected later. (Q8): Scientific law describes the relationship between observable phenomenon. For example, the speed of sound is faster in water than in air. Theory explains the phenomenon, due to the different density of particles in water and air. 2658(Q7): Yes. The scientific knowledge is tentative and subject to change. It will be changed according to the advancement of technology, such as the theory of evolution. (Q8): They are different. Laws is natural phenomenon, such as law of gravity. Theory explains the phenomenon, but it may not be fully correct, such as the theory of evolution.

Theme 6: Using examples from the previous learning

As shown in Table 37, for those students using examples from the previous learning to explain their answers in the post-test questionnaire, it was interesting to find out that more of them were from the SSI group than the HOS group. 17 out of 24 students from the SSI group (70.8%) were able to use examples recalled from previous learning to explain their choices, while only 6 out of 17 students from HOS group (35.3%) were able explain their choices in the post-test questionnaire based on evidence drawing from their previous learning.

Considering Themes 5 and 6 as a whole, for the HOS group, students seemed to make more references to historical cases as evidence to support their assertions or arguments across different NOS tenets. The examples that they used to explain their choices were diversified, ranging from the Darwinian theory of evolution, Newton’s law, the shape of the earth, heliocentric, discovery of cell, law of gravity, and DNA parentage testing. The probable reason why HOS students used historical cases more frequently was that the content of the lesson provided a number of concrete episodes of how science actually developed, which might reflect the ways of students’ thinking from observation to conclusion (Yip, 2006).

By contrast, in the SSI group, there was a greater tendency for the students to use more recent issues or examples to substantiate their claims. The majority of students raised the shape of the earth as the example to explain their choices. Some of them used the theory of evolution, the law of gravity, gastric ulcer, cloning technology, treatment of H5N1, the invention of light bulb, Mendel’s law, the discovery of the cell, and the speed of sound. Some examples might be drawn from their junior form integrated science which they have learnt years ago, such as the law of gravity, the invention of light bulb and the speed of sound. The other examples might be drawn from their senior form biology lessons such as the theory of evolution, Mendel’s law, the discovery of the cell, gastric ulcer, cloning technology, and the treatment of H5N1. This result was consistent with the finding by Walker & Ziedler (2007). The two researchers found that through the SSI approach, students were able to use evidence to explain their choices after the intervention, it may be that an advantage of using SSI to teach the NOS is that it could encourage students to use evidence and example to explain their choices.

The above themes unveiled from the post-test questionnaire were ideas extracted from the students' responses to those items that assessed their understanding of the seven NOS tenets. A more systematic mapping was conducted as to how individual themes were related to each of the NOS tenets. This was done by matching these themes with the different tenets of NOS according to the question items in which these themes occurred, and the examples of students' utterances provided in Tables 32 - 37. The results of the mapping were displayed in Table 38.

Table 38 Frequency of occurrence of themes related to the seven tenets of NOS that are identified from students' responses to the post-test VNOS-D+ questionnaire

	Themes related to different NOS tenets that are identified for different teaching approaches	
NOS Tenets	HOS (17 students)	SSI (24 students)
1. Empirical basis	-	-
2. Observation & inference	Knowing is seeing (47%) Believing technology / machine (29%) Believing authority (6%)	Knowing is seeing (29%) Believing technology / machine (8%) Believing authority (4%)
3. Theory & Law	Using examples from the lesson (12%) Using examples from previous learning (6%)	Using examples from previous learning (21%)
4. Creativity & imagination	Using examples from previous learning (24%) Using examples from lesson (6%)	Using examples from previous learning (13%)
5. Tentativeness	Using examples from the lesson (12%) Using examples from previous learning (12%) Believing technology / machine (6%)	Using examples from previous learning (63%)
6. Subjectivity	Incomplete understanding of the role of subjectivity in science (24%)	Incomplete understanding of the role of subjectivity in science (38%)
7. Social & cultural embedded	Using examples from previous learning (6%)	Using examples from the lesson (29%)

It was found that no theme was identified in relation to the tenet of empirical basis. There were three themes associated with the tenet of observation & inference, both for the HOS and SSI groups. These themes are: *knowing is seeing*, *believing technology / machine* and *believing authority's claim*. More students from the HOS group identified with the theme of *knowing is seeing* than SSI students. For the tenet of theory & law, two themes were identified for the HOS group, which are: *using examples from the lesson* and *using examples from the previous learning*, whereas, only one theme was conspicuous for the SSI group, which is *using examples* *from previous learning*. Despite this, this theme was more frequently occurred in the SSI group than in the HOS group. This seems to imply that the students in the SSI group were more ready to use examples to support their claim.

For the tenet of creativity & imagination, two themes were identified in the HOS group, which were *using examples from previous learning* and *using examples from the lesson*. However, only one theme was found in the SSI group, which was *using examples from previous learning*. Overall, there were a relatively higher percentage of HOS students who used *examples to support their claim* in this tenet than their counterparts in the SSI group.

For the tenet of tentativeness, three themes were unveiled in the HOS group, which were *using examples from the lesson*, *using examples from the previous learning* and *believing in technology / machine*. Whereas only one theme was obvious in the SSI group, which was *using examples from previous learning*, yet at a higher frequency of occurrence than for the HOS group. It may thus be concluded that SSI students were more able to apply examples that they have learnt to support their claims.

As to the tenet of subjectivity, only one theme was found in both groups, which was incomplete understanding of the role of subjectivity in science. A relatively higher percentage of occurrence of this theme was recorded in both groups, with 24% in the HOS and 38% in the SSI group. More students in the SSI group than the HOS group showed incomplete understanding of subjectivity in that they tended to regard subjectivity as permeating scientific knowledge regardless of the stages of development of the knowledge. This implies that those students tended to regard subjectivity as a limitation, rather than as a starting point for scientific inquiry in search of evidence for making science more objective.

For the tenet of social & cultural embedded, there was only a singular theme identified from both groups. For the HOS group, it was *using examples from previous learning*, while for the SSI group, it was *using examples from the lesson.*

To sum up, a higher percentage of SSI students were able to use examples from previous learning to explain the NOS tenets, such as theory and law, creativity and imagination as well as tentativeness. A plausible explanation might be that the SSI students have learned how to use examples to support their views or ideas during the discussion process among group mates to convince others to believe their stands. For example, in the topic of human genome project, students were trained to define 'law' by abnormality of fetus due to abnormal gene, since they knew that 'law' is a statement or description of the relationship among the observable phenomena, such as the case of Mendel's second law, which describes the separation of homologous chromosome during meiotic cell division. On the other hand, both groups displayed relatively high percentage for incomplete understanding of the role of subjectivity in science. In the HOS intervention, the notion of subjectivity was discussed during the second lesson regarding the prediction of the structure of DNA by different scientists during 1950s. It was like telling to students a story about the discovery process of DNA by different scientists using the same set of data about DNA. Students were told that the different predictions by different scientists might be due to differences in knowledge background of different scientists. However, they were not aware of the exact difference between the scientists' knowledge background to appreciate the tenet of subjectivity. A similar situation was observed in the SSI group, in which, students were divided into two groups to discuss the trend of the outbreak of Dengue fever in Hong Kong, and to come up with their own conclusion. Students in this group also have not generated different conclusions from the data. The reason may be again due to their lack of different scientific knowledge about the spread of disease. resulting in mind sets of scientists, which is regarded as a basis of subjectivity.

4.5 Data from semi-structured interview

In this study, the semi-structured interview was aimed to probe more deeply into the students' ideas about NOS by asking them questions based on their responses provided in the post-test questionnaire. This could help to elicit the students' thoughts about NOS and any change in their thoughts after the intervention. After a systematic review of all the transcripts, emergent themes were generated, and relevant anecdotal evidence was displayed as evidence to support the validity of those themes. The interview data also allows the researcher to triangulate both the quantitative and qualitative findings generated from the VNOS-D+ questionnaire as reported in the previous sections. From the analysis of the interview data, themes were categorized that bear a considerable degree of similarity to those abstracted from the questionnaire. For example, students believed scientific knowledge development was based on fact and the fact could be seen, which is similar to the theme of "knowing is seeing", which appeared rather frequently in the analysis of the post-test questionnaire. To illustrate this similarity, the interview extracts cited below show on what basis an SSI student (2653) perceive the internal structure of the earth.

"Knowing is seeing"

T: Teacher

S: 2653-SSI

T: Do you know there are several layers of the earth?

S: I do know.

T: Do you believe it?

S: I don't believe it.

T: Why?

S: Because no one could cut open the earth to see.

The dialogue between the teacher and student reproduced above was consistent with the finding in the post-test questionnaire with respect to the students' conception that seeing is believing. Put it oppositely, they tended not to believe in things that they could not see. Hence, seeing seems to be the only way that makes them believe in scientific knowledge. A possible consequence is that, those students bearing such conception may have a greater likelihood to reject the role and importance of imagination and creativity in the development of scientific knowledge, another basic tenet of NOS. The interview extracts below illustrated how an SSI student (2653) had his idea clarified during the interview.

T: How do people draw the clear detailed layers of earth?

S: erh… … by imagination.

T: Can we object it?

S: The chance is very low.

T: Why?

S: Because the core is lava, we cannot cut the earth to see.

T: The people claimed that it is lava, have you been there?

S: No.

T: It may not be the lava.

S: make a hole

T: Why people guess there is lava in the core?

S: because there is volcano explosion. They think lava coming from the underground.

At the beginning, student 2653 was also holding very strong idea of "knowing is seeing". There were three times that the student 2653 mentioned, "We cannot see inside the earth, so we could not oppose the idea of earth structure." Even though he knew the structure is created by imagination, he knew that if we need to reject an existing knowledge, we should have a very concrete and powerful new evidence to support our assertion, such as evidence gained from observation. Nevertheless, he was able to infer that since lava will flow out to the earth surface following a volcano explosion, the lava had to be come from underground, that is the inner core of the earth.

<u>Support for tentativeness</u>

It was found that some students were not able to provide explanations to support their belief in that science knowledge would change in future. The majority of the students just replied that they believed it would be changed, but without detailed explanation. They were only able to explain that this was due to technology advancement. According to the post-test questionnaire analysis, it was found that SSI students could give more examples to support their ideas on the tentativeness of NOS than HOS students. The interview transcript below illustrated how a student (1613) responded to the concept of tentativeness.

T: Teacher

S: 1613-HOS

T: Thanks. Scientist developed science knowledge. Do you think it will change in the future?

S: Yes, it will. Since our science … our science… is keeping …. to create new knowledge and infer their own ideas.

He just believed it, but he didn't know why he believed in that science knowledge would change due to technology development or more new discoveries. He just trusted what he believes. The reason may be that since our society keep changing every day, it made them feel that change is natural. The interview transcript below illustrates how the student (2650) from the SSI group responded to the concept of tentativeness.

T: Teacher

S: 2650 – SSI

T: Here is your post-test questionnaire. There are many theories which were raised by scientists. Do you think they will change or not?

S: Because those theories were created by scientists based on subjective views. Those knowledge may not come from experiment. It is created through their observations and imagination. If there is technology advancement, it may change the existing view of knowledge.

He knew the scientific knowledge would be changed due to technology advancement, but stopped short of providing an example to support his claim.

Imagination and Creativity

The interview transcript below illustrated how a student (2652) from the SSI group displayed the concept of imagination and creativity and extended to another concept.

T: Teacher

S: 2652 – SSI

T: Do you think imagination is required in scientific research?

S: yes.

T: Why?

S: If you don't imagine, then you will not… …

T: will not. What?

S: ha ha. Then you will not observe it.

T: Could you give any examples? Or experiment needed imagination?

S: cell membrane.

T: Do you mean the structure of cell membrane was generated by imagination?

S: yes.

The student admitted that NOS involves the concept of imagination. He only gave the name of the example, cell membrane. Since they learnt the structure of cell membrane before, that is, the fluid mosaic model, during their regular biology class. So, he remembered the model was constructed out of imagination, but he failed to give a comprehensive answer during interview. The interview kept going as follows.

> T: How can we investigate the structure of the cell membrane?
>
> S: by the microscope?
>
> T: if we know the structure of cell membrane is not true. Do we still use the microscope to check it?
>
> S: no.
>
> T: Could the microscope help us see the structure of cell membrane?
>
> S: it can't see.
>
> T: If we really want to know the structure of cell membrane, but the microscope cannot do it. What should we do?
>
> S: by imagination.
>
> T: what should you do to discover or invent something to help you?
>
> S: invent the machine to see the structure of cell membrane.
>
> T: do you mean that machine should be more powerful than the microscope to observe the structure of cell membrane?
>
> S: Yes.

The researcher would like to challenge him about the tentativeness of scientific knowledge. But the student failed to point out the change of scientific knowledge may require technology advancement to make new discoveries possible. He needed the researcher to guide him to the answer. But actually, he should have already learned that during the intervention. This revealed that the student has not fully understood the role of technology advancement in reinforcing the tentativeness of scientific knowledge as a tenet of NOS. This may be due to failure of the intervention to help the student develop this concept.

Believing in authority

It was found that students believed in the knowledge from books, magazines, or textbooks. When asked about the structure of the Earth with several layers, from the core to the crust. Most of them replied that they believed the description of the several layers of the Earth, since they have seen the diagram from books which might be science textbooks or the books which were borrowed from library. The interview transcript below illustrated the student (2654) from the SSI group how to respond to the question about the model of the earth.

T: Teacher

S: 2654 - SSI

T: Have you seen the model of earth?

S: Yes.

T: There are several layers of the earth. How many layers?

S: three layers.

T: How do you know?

S: I read from the diagram in the book.

Here, the student also cited the knowledge from the book. Despite this, he still believed that scientific knowledge would be changed due to technology advancement.

Although, he was asked by the interviewer further, “Did you think anyone can go into the deeper ground of the Earth? “He replied that no one has been able to go into the deeper ground before. Then the interviewer asked him how you knew the distribution of those layers must be correct. He replied that the diagram in the book must be correct. According to Bråten, Britt, Strømsø & Rouet (2011), even for undergraduates, they would treat the information from textbook as reliable and trustworthy, it was because they have learned to believe in the textbook as a very important authority during their schooling. The present findings reflect that our primary and junior secondary students are now learning to trust the textbook. That was why they often ended the interview by saying, “It is told by the textbook”. The interview transcript below illustrated how the student 2650 from the SSI responded to the question about the appearance of dinosaur.

T: Teacher

S: 2650 – SSI

T: Do you believe there were dinosaur?

S: I believe.

T: Why do you believe it?

S: Because scientists had certain knowledge, and also there are some fossil records, so it is believable and trustable. And scientists infer those records related to dinosaur. That’s why I believe.

T: But do you think everything the scientist says must be correct?

S: not sure.

T: But why do you believe anything done by scientists before?

S: Because they have knowledge more than mine.

Other than perceiving textbook as the authority, students tended to regard the scientist as another authority, since they thought scientists possess more knowledge than their own. It was found that students were not familiar with science stories or science news. This tendency is consistent with the students' responses to the VNOS-D+ questionnaire. When asked to provide justifications for their choices in the questionnaire, students usually cited science stories by making reference to the story title only and without further elaboration.

4.6 RQ3: Are there any influences that gender or biology performance have on the students' learning of NOS using either the HOS or SSI approach?

4.6.1 Influence of biology performance on understanding of NOS

The biology academic performance, which reflects student ability to learn biology, is regarded as a potential factor that may mediate the effect of any teaching approach, in this case, the HOS or SSI approach, on developing students' understanding of NOS. The two-way ANCOVA was used to test the difference between the two groups of students, who differed in their biology performance, in learning NOS. The result was showed in Table 39.

Table 39 Two-way ANCOVA results showing the relationship between biology performance and teaching approach in learning NOS

Tenets of NOS	Source	Univariate Test Statistic	η^2
1 Empirical basis	Approach * biology performance	F(1,36)=0.092, p=0.764	0.003
2 Observation & inference	Approach * biology performance	F(1,36)=0.000, p=0.994	0.000
3 Theories & Laws	Approach * biology performance	F(1,36)=0.418, p=0.522	0.011
4 Creativity & imagination	Approach * biology performance	F(1,36)=0.228, p=0.636	0.006
5 Tentative	Approach * biology performance	F(1,36)=0.004, p=0.947	0.000
6 Subjective	Approach * biology performance	F(1,36)=1.990, p=0.167	0.052
7 Society & cultural embedded	Approach * biology performance	F(1,36)=0.035, p=0.852	0.001

As shown in Table 39, the results of the two-ways ANCOVA indicate that there was no statistically significant interaction between students' biology performance and the two teaching approaches used in this study.

4.6.2 Correlation between biology achievement and understanding of NOS

The post-test results from SSI group and HOS group were analyzed by Pearson's correlation to test whether there was any correlation between students' biology achievement and their understanding of the seven tenets of NOS using different teaching approaches. Table 40 displayed the correlation of biology achievement with student performance in the post-test for the SSI group. Table 42 displayed the correlation of biology achievement with student performance in the post-test for the HOS group.

To corroborate the correlational findings based on the students' post-test score, the gain in score by students with different biology performance in the two treatment groups were also analyzed by Pearson's correlation. Table 41 displayed the correlation of students' biology achievement with their gain in score in the post-test for the SSI group. Table 43 displayed the correlation of students' biology achievement with their gain in score in the post-test for the HOS group.

Table 40 Correlation of students' biology achievement with their post-test score for the SSI group

Tenet of NOS	Pearson correlation	Sig. (2-tailed)	N
1. Empirical basis	-0.359	0.085	24
2. Observation & inference	-0.317	0.131	24
3. Theory & law	0.171	0.425	24
4. Creativity & imagination	0.079	0.714	24
5. Tentativeness	0.138	0.521	24
6. Subjectivity	-0.313	0.136	24
7. Social & cultural embedded	-0.180	0.399	24

As shown in Table 40, no statistically significant correlation was obtained between the students' performance in the post-test on all the NOS tenets and their biology performance for the SSI group.

Table 41 Correlation of students' biology achievement with their gain in score from pre-test to post-test for the SSI group

Tenet of NOS	Pearson correlation	Sig. (2-tailed)	N
1. Empirical basis	-0.669**	0.000	24
2. Observation & inference	-0.274	0.194	24
3. Theory & law	0.353	0.091	24
4. Creativity & imagination	0.213	0.317	24
5. Tentativeness	0.030	0.891	24
6. Subjectivity	-0.208	0.329	24
7. Social & cultural embedded	-0.339	0.105	24

*Note ** Correlation is significant at the 0.01 level (2-tailed)*

AS shown by Table 41, there was a statistically significant, but negative correlation between the gain in score for the tenet on empirical basis and biology performance for the SSI group. Aside from that, no statistically significant correlation was obtained between the improvement of the learning for all other tenets and students' biology performance for this student group.

Table 42 Correlation of students' biology achievement with their post-test score for the HOS group

Tenet of NOS	Pearson correlation	Sig. (2-tailed)	N
1. Empirical basis	0.437	0.080	17
2. Observation & inference	0.056	0.832	17
3. Theory & law	0.655**	0.004	17
4. Creativity & imagination	0.288	0.262	17
5. Tentativeness	-0.044	0.866	17
6. Subjectivity	0.290	0.259	17
7. Social & cultural embedded	0.435	0.081	17

*Note ** Correlation is significant at the 0.01 level (2-tailed)*

As shown in Table 42, there was a statistically significant positive correlation between the students' performance in the tenet of theory & law and their biology performance for the HOS group. Again, there was no statistically significant correlation between the students' performance in the other tenets and their biology performance.

Table 43 Correlation of students' biology achievement with their gain in score from pre-test to post-test for the HOS group

Tenet of NOS	Pearson correlation	Sig. (2-tailed)	N
1. Empirical basis	0.067	0.800	17
2. Observation & inference	0.098	0.708	17
3. Theory & law	0.598**	0.011	17
4. Creativity & imagination	0.068	0.794	17
5. Tentativeness	-0.130	0.618	17
6. Subjectivity	0.365	0.150	17
7. Social & cultural embedded	0.385	0.127	17

*Note ** Correlation is significant at the 0.05 level (2-tailed)*

As shown in Table 43, there was a statistically significant positive correlation between the improvement of learning the tenet of theory & law and biology performance for the HOS group. However, there was no statistically significant correlation between the students' biology performance and their improvement in learning other NOS tenets.

The above findings showed that although there was no correlation between the students' biology achievement and their understanding of NOS tenets in the SSI group after the intervention as reflected by their post-test results, there was a negative statistically significant correlation (r =-.669, n =24, p =.000) between the students' biology achievement and their improvement in the NOS tenet of empirical basis for the SSI group after the intervention. This could be taken to imply that the lower achievers in Biology benefitted more than the higher achievers in learning the tenet of empirical basis when the SSI teaching approach was adopted.

However, for the HOS group, both the students' understanding of the theory and law tenet of NOS as reflected by their post-test score and the students' improvement in this tenet as shown by their gain in score after the intervention were found to be correlated with the students' biology achievement. The correlation, which was strongly positive, was statistically significant (r =.655, n =17, p =.004). And Table 43 shows that there was positive statistically significant correlation (r =.598, n =17, p =.011). These findings imply that the higher achievers in biology seemed to benefit more from the HOS teaching approach than the lower achievers in biology with respect to the learning of the tenet of theory and law.

4.6.3 Gender difference on students' understanding of NOS using different teaching approaches

The potential mediating effect of the gender factor on the influence of different teaching approaches on students' learning of NOS was also taken into consideration in this study. The two-way ANCOVA was used to test the difference between the interaction between the two groups of students in learning NOS and gender. The result of the analysis was shown in Table 44.

Table 44 Two-way ANCOVA results showing the relationship between differences in gender and teaching approach in learning different NOS tenets

Tenets of NOS	Source	Univariate Test Statistic	η^2
1 Empirical basis	Approach	F(1,36)=0.361, p=0.552	0.010
	Gender	F(1,36)=1.964, p=0.170	0.052
	Approach * gender	F(1,36)=1.324, p=0.258	0.035
2 Observation & inference	Approach	F(1,36)=0.791, p=0.380	0.022
	Gender	F(1,36)=0.168, p=0.684	0.005
	Approach * gender	F(1,36)=2.378, p=0.132	0.062
3 Theories & laws	Approach	F(1,36)=2.199, p=0.147	0.058
	Gender	F(1,36)=3.321, p=0.077	0.084
	Approach * gender	F(1,36)=0.062, p=0.804	0.002
4 Creativity & imagination	Approach	F(1,36)=0.825, p=0.370	0.022
	Gender	F(1,36)=3.373, p=0.075	0.086
	Approach * gender	F(1,36)=0.030, p=0.957	0.000
5 Tentativeness	Approach	F(1,36)=0.835, p=0.367	0.023
	Gender	F(1,36)=2.619, p=0.114	0.068
	Approach * gender	F(1,36)=0.061, p=0.806	0.002
6 Subjectivity	Approach	F(1,36)=0.390, p=0.536	0.011
	Gender	F(1,36)=0.001, p=0.976	0.000
	Approach * gender	F(1,36)=0.926, p=0.342	0.025
7 Society & cultural embedded	Approach	F(1,36)=1.528, p=0.224	0.041
	Gender	F(1,36)=1.384, p=0.247	0.037
	Approach * gender	F(1,36)=1.950, p=0.171	0.051

As shown by Table 44, there was no statistically significant interaction between gender and teaching approaches for all the seven tenets of NOS according to the analysis using two-ways ANCOVA. Also, there was no statistically significant difference between the two genders in learning NOS, implying that gender is not a significant factor mediating students' understanding of NOS under different teaching approaches.

4.7 Summary

From the findings presented in this chapter, several findings were worthy of consideration, which provide evidence for answering the research questions. First, the SSI approach could successfully improve students' understanding of NOS with respect to the seven tenets under study. This finding is consistent with the studies conducted in other countries or cities. According to the results of the paired *t*-test, the SSI teaching approach was able to improve Hong Kong senior secondary biology students in learning all the seven tenets of NOS with statistically significant learning outcomes. For the HOS treatment group, the same statistically significant findings were obtained, implying that the effect of the HOS approach was comparable with that of the SSI approach in promoting students' understanding of NOS from pre-test through to the post-test.

As to the question of whether there is any relationship among these seven tenets of NOS, it was found that there was a strong positive correlation between improvement in the observation and inference tenet and improvement in the subjectivity tenet in SSI teaching approach. This implies that those students who showed improvement in the observation and inference tenet also showed improvement in the subjectivity tenet. For the HOS teaching approach, in addition to the observation and inference tenet, a strongly positive correlation was also obtained between observation and inference and subjectivity. The latter might be due to a greater awareness among students in the HOS group of the societal and cultural contexts as they were exposed to continuous scientific discoveries in the same field across a wide historical spectrum. These inferences will be further discussed in the next chapter.

When ANCOVA was used to test the difference between both teaching approaches in improving students' understanding of NOS, no statistically significant difference was found between either the HOS or SSI teaching approach and the improvement of understanding of all the seven tenets of NOS. This finding shows that the HOS and SSI approach appeared to have comparable effect on improving students' learning of NOS, hence increasing their understanding of the seven NOS tenets under study.

According to the semi-structured interview, the results are rather surprising in that most of interviewees seemed to trust scientific claims due to their belief in authority, such as textbooks, scientists, teachers, magazines, etc. This is evidenced by the oft-cited statement made by the interviewees toward the end of the interviews that "it is told by textbook". Moreover, they also exhibited the tendency of knowing by seeing, implying that they would only believe in scientific knowledge that could be readily observed. This notion was exemplified by such teacher-student dialogues as "Teacher: Why do you believe? Student: Because I saw it before; teacher: Why don't you believe it? Student: Because I didn't see it before." This seems to be consistent with the findings in the post-test VNOS-D+ questionnaire. From the questionnaire findings, 58.8% and 29.2% of students from the HOS and SSI group respectively responded that "knowing is seeing". This might explain why those students tended to reject creativity and imagination as a component of the nature of science. However, students tended to believe in concepts they saw in the textbook or magazine, which they might have associated with authoritative information sources.

Besides, students from the HOS group tended to make more reference to historical cases as evidence to support their assertions or arguments across different NOS tenets. They also tended to consider technological development, and the availability or unavailability of technology as a determining factor or constraint for the development of science. On the other side, students from the SSI group showed a greater tendency to use more recent issues or examples to substantiate their claims. It is also worth noting that overall, students from the SSI group tended to use more examples, including current and historical ones, to support their claims than their counterparts in the HOS group.

Are there any factors affecting students learning of NOS other than the teaching approach, such as biology achievement and gender? According to the findings of the 2-way ANCOVA on possible interaction effects between the teaching approach and gender or students' biology achievement, no statistically significant differences were found between the teaching approach, either the HOS or the SSI approach, and gender or biology achievement regarding students' understanding of all the seven tenets of NOS.

However, according to the Pearson's correlation, there was a statistically significant positive correlation between students' understanding of the tenet of theories and laws as judged by the post-test and biology achievement for the HOS group. This implies that, students with higher biology achievers would learn the tenet of theories and laws to a better degree using the HOS approach than low biology achievers. No similar positive correlation was found in the SSI group. However, on the SSI side, there was a statistically significant, but negative correlation between the gain in score for the tenet of empirical basis and biology performance.

Finally, there was no statistically significant interaction between gender and teaching approaches on all the seven tenets of NOS according to the findings of the two-way ANCOVA. Similarly, there was no statistically significant difference between the two genders in learning NOS. These findings were consistent with Dogan & Abd-El-Khalick (2008) and Liu & Tsai (2008), who reported that there was no gender difference in students' understanding of any of the tenets of NOS.

5 Discussion and Conclusions

5.1 Introduction

This study was motivated by the very poor performance of senior secondary biology students in the Hong Kong DSE biology examination. It aimed to address the problem by studying alternative teaching approaches that could enhance the learning of NOS. According to the findings reported in the previous chapter, the participants in general showed undesirably low score in the pre-test for all the seven tenets of NOS before the interventions, namely the HOS and SSI approach. From the literature review presented in Chapter 2, it was suggested that the SSI approach might be a viable alternative to the HOS approach for improving students learning NOS. This study attempted to apply the SSI approach in the teaching environment of Hong Kong in teaching senior secondary biology students for a better understanding of NOS.

The findings of this study showed that SSI was able to improve Hong Kong senior secondary biology students' understanding of NOS, which was comparable to the improvement achieved by students through the HOS approach, that is, the existing approach recommended for Hong Kong schools. As to the relationships among the seven tenets of NOS under study as claimed by some researches in literature, it was found that there was a positive correlation between *observation & inference* and *subjectivity* for both the SSI and HOS teaching approaches. Additionally, for the HOS but not the SSI approach, the *observation & inference* tenet was also positively associated with the *social and cultural embeddedness* tenet. As to which teaching approach, the SSI or HOS approach, was more effective in enhancing students' understanding of the seven NOS tenets, no statistically significant differences were found between the two teaching approaches. Based on a detailed examination of the written responses of the students from both groups to the VNOS-D+ questionnaire, and the interview data, a number of themes were identified about students' thoughts, which seemed to have influenced their conceptions of NOS. Finally, it was found that there was a positive association between biology achievement and understanding of the tenet of *theory and law* for the HOS group but not the SSI group. However, there was a strongly negative association between students' biology achievement with their improvement in understanding the tenet of empirical basis. Yet, for both teaching approaches, there was no association between gender and their understanding of the tenets of NOS.

5.2 Students' initial NOS concepts before intervention

The quantitative findings revealed rather low pre-test scores on students' understanding of the seven NOS tenets for both treatment groups. This seems to be consistent with the poor results obtained by the HKDSE biology candidates on NOS as discussed in Chapters 1 and 2. The low pre-test score came as a surprise as curriculum reform was implemented in the junior science curriculum since 2002 that has placed great emphasis on scientific investigation skills practiced by scientists. The junior curriculum seems not to have exerted a great impact after more than 15 years of implementation.

The students' weak performance in the pre-test may imply that a mere emphasis of the junior curriculum on skills involved in scientific practice may not be sufficient to enhance students' understanding of NOS. In view of the relative merit of explicit intervention over implicit intervention in implementing NOS education, the two treatment methods or teaching designs, HOS-oriented and SSI-oriented, need to be specially designed to teach NOS in an explicit manner (Bell et al., 2011; Eastwood et al., 2012; Matkins and Bell, 2007; Peters, 2012). A lack of understanding of NOS at the junior level would not be conducive to the continuous development of students' understanding of NOS in senior science. The lack of examination requirement at the junior level may be one of the causes for this not so favorable state. As noted by Lederman (2007), even though teachers were able to teach NOS to students, if they were not motivated to do so because of lack of examination stress, they would rather spend more time and effort on those materials that would be assessed in examinations.

Despite the above limitation, from the perspective of curriculum design, the reform of the junior form science curriculum has placed new emphases on scientific investigation skills (Yip, 2006). This, to a certain degree, could be regarded as necessary groundwork for the senior form students to learn NOS.

Science teachers are expected to develop students' knowledge of NOS. However, Wong, Wan & Cheng (2011) indicated that Hong Kong teachers had seldom been taught the concepts of NOS during their schooling, so they might have little ideas about NOS and did not know how to teach the concepts of NOS to students effectively. Moreover, it is a common practice for teachers to rely heavily on the textbook to deliver lessons to students. So, for those contents that did not appear in the textbook, they are likely to be skipped. As a matter of fact, most of the knowledge that appears in current science textbooks focused mainly on the delivery of science conceptual knowledge (Yip, 2006). All these factors are likely to have exerted an impact on the learning of NOS by Hong Kong students. Nevertheless, more research is needed to validate these hypotheses.

5.3 Effectiveness of the HOS approach

According to the findings of the statistical analysis based on the paired *t*-test, the HOS group showed statistically significant improvement in their understanding of all the seven tenets of NOS after the intervention. This implies that the existing teaching approach was capable of improving students' understanding NOS in the HK classroom context. This echoes Nur and Fitnat (2015)'s finding that the HOS teaching approach could improve students' NOS conception in general, but the improvement was not the same in all dimensions of NOS. When the students' responses to the VNOS-D+ questionnaire items were subject to more detailed qualitative analysis, it was shown that the HOS group appeared to make more reference to historical cases as evidence to support their assertions or arguments across different NOS tenets. The examples that they used to explain their choices were diversified, which range from the theory of evolution, Newton's law, the shape of the earth, the heliocentric view, the discovery of cell, the law of gravity, to DNA parentage testing. A possible reason for the HOS group to use more historical cases was that the HOS lessons had provided students with concrete episodes of how science actually works, which might parallel the ways in which students think like scientists in experiencing the process of discovering (Yip, 2006). Also, the post-test finding that students expressed greater awareness of the influence of society and culture on NOS might be a result of the lesson design which exposed students to the arduous process of argumentation amongst scientists as influenced by cultural factors. For instance, Mendel's idea was initially rejected by the scientific community before sufficient evidence about meiotic cell division was obtained to support his assertion later on.

Moreover, the results of the quantitative analysis showed that for the HOS group, students' understanding of observation and inference was positively associated with the tenet of social and cultural embedded. This might be due to a greater awareness among students in the HOS group of the societal and cultural contexts as during the intervention, they were exposed to scientific discoveries in the same field across a historical spectrum with changing societal and cultural contexts. For example, in the third lesson using the HOS approach, students were told about the story of Edward Jenner's discovery of a vaccine to treat the smallpox. The story emphasizes the importance of the observation that milkmaids who suffered from the mild disease of cowpox had never become infected with smallpox. This observation led Jenner to infer that cowpox might confer immunity against smallpox. Jenner's meticulous observation and ingenious inference was discussed against the backdrop of a unique social and cultural context - the infectious disease of smallpox could not be effectively prevented, and cowpox was prevalent among milkmaids at that time as a result of milking of infected cows, leading to immunity against smallpox.

Furthermore, the interview findings have provided insights into why and how the students were able to show improved performance regarding the tenet of tentativeness from pre-test to post-test. A plausible explanation may be that the concrete episodes of how science actually worked in discovering the structure of DNA during 1950s, such as new discoveries made possible by such technology advancement as X-ray crystallography, might have developed in students the idea that science is tentative, and technological advancements will bring about advancements in science. Moreover, the course design highlighting the change in the knowledge of DNA from time to time also clearly reflects the tentativeness of NOS.

Lastly, the HOS approach also exerted an impact on students' understanding of the tenet of creativity and imagination. Such improvement might be due to students' appreciation of Watson and Crick for producing the spectacular 3-dimensional model of DNA out of creativity and imagination. Watson and Crick were able to construct the 3-dimensional double helix model of DNA based on the previous findings of Maurice Wilkins and Rosalind Franklin, who made use of X-ray crystallography to produce the scattering of DNA.

5.4 Effectiveness of the SSI approach

According to the result, the SSI group showed significant improvement in their understanding of NOS from the pre-test test through to post-test as revealed by the paired *t*-test. This finding implies that like the HOS approach, the SSI approach was capable of improving students' understanding of NOS in the classroom context. However, unlike the HOS approach, which is recommended by the curriculum planners as an approach to deliver NOS to students (CDC and HKEAA, 2007), there were no guidelines on the use of socio-scientific issues to deliver the concepts of NOS. Wong et al. (2011) undertook a study on the use of SSI to teach pre-service teachers about the concept of NOS. Their intervention found that teachers possessed relevant NOS concepts after they had received input on NOS for more than 18 months. Their finding echoes the one reported by Bell et al. (2011), which showed that those pre-service teachers from the US, after teaching with NOS explicitly by SSI approach displayed significantly positive learning outcomes in their views of NOS. There have been studies in the past targeting at school students like the present one, which suggested that SSI could improve high school students learning of the concepts of NOS (e.g., Eastwood et al., 2012; Walker & Zeidler, 2007; Zeidler et al., 2002). The findings of the present study lend further support to the utility of the SSI approach in promoting NOS education. In the present study, senior secondary biology students' understanding of all the seven tenets of NOS improved after intervention using the SSI approach, which made use of the DNA model, human genome project, together with the spreading of two infectious diseases (Dengue fever and Avian influenzas) as the context to assist students in developing the essential tenets of NOS. These more recent issues are able to exemplify the tremendous impact of science on modern society. Moreover, in addition to the quantitative data which shows significant improvement of students' understanding of NOS from the post-test to pre-test result, the qualitative data show that the minds of students were likely to be affected by the topics selected and lesson design during SSI intervention. For example, student' response 2561 in the post-test interview expressed that to curb the outbreak of bird flu, the government needed to do more researches to invent vaccines to prevent the spread of the disease. There is also a need to find out the source of the outbreak to control the disease. From the above response, students seemed to have admitted implicitly scientific development might be affected by the social milieu. In this way, the course design was likely to have exerted considerable impact on students in their learning of NOS.

5.5 Association among the seven tenets in the two teaching approaches

According to Schwartz, Lederman & Crawford (2004), the seven tenets of NOS should be considered in close interaction with each other. That is to say, they are interdependent. For example, the *tentativeness* of NOS stems from the generation of scientific knowledge by *empirical observation and inference*. All new data and existing data would be reconsidered by scientists, leading to changes to the existing scientific knowledge. On the other hand, culture and society may play a role in affecting *subjectivity* and hence influencing the selection of theoretical frameworks and research questions, and the formulation of hypotheses.

For the SSI teaching group, there was a strong positive correlation between the gain in understanding of *observation & inference* and of *subjectivity* (r = .506). This means that a greater gain in students' understanding of the *observation & inference* tenet would be accompanied by a greater gain in understanding of the *subjectivity* tenet. This may imply that students' perceived inference or even observation as being subjective. Conversely it is also possible that one's subjectivity may influence one's observation and inferences made. This finding echoes a similar finding reported by Schwartz et al. (2004). From my point of view, human factors were inevitably involved in these two tenets. This is easy to be understood in case of observation, which is highly dependent on the perception of the sense organs and subsequent interpretation by the brain, which again depends on an array of factors. One's inference based on one's observation is arguably even more subjective. Hence, subjectivity which refers to the selective interpretation or judgment or choice made by the investigator, is likely to be stemmed from one's subjective observation and inference. Both tenets are also likely to be affected by the individual's prior knowledge in science, such that understanding of the tenet of observation & inference may affect the tenet of subjectivity, or vice versa.

In comparison with the SSI group, the HOS treatment group also showed a strongly positive correlation between improvement in understanding the *observation & inference* and the *subjectivity* tenet (r = .512), thus providing further evidence to support the inter-relationship of these two tenets. In addition, for the HOS group, a strong positive correlation was also found between improvement in the *observation & inferenc*e tenet and the *social & cultural embedded* tenet (r = .572). This means that for those students that showed greater improvement in the *observation* tenet, they also showed a corresponding degree of improvement in the *social and cultural embedded* tenet. This additional positive association exhibited by the HOS group was probably related to the teaching materials used by this treatment group. HOS students were exposed explicitly to historical discoveries that were in close association with the social and cultural contexts in which these discoveries were made. Moreover, these discoveries had very likely produced a strong impact on society, bringing substantive changes to human livelihood.

Thus, this mutual interaction between science and society might have led students to a greater awareness of the role played by societal and cultural contexts in scientific discoveries, and vice versa as they moved across the historical spectrum of scientific and social development in the learning process.

According to the findings, both treatment groups showed improvements in their understanding of all the seven NOS tenets from the pre-test to post-test. However, no statistically significant difference was found between the effect of the HOS and SSI approach based on the test of ANCOVA, with the pre-test test score set as a covariate. Despite this, further insights could be drawn about the similarities and nuanced differences between the two treatment groups based on the qualitative responses made by the two groups to individual items in the VNOS-D+ questionnaire.

5.6 Insights drawn from qualitative data

Several themes on students' nuanced ideas about science in relation to the seven NOS tenets were identified from the qualitative data analysis on the post-test questionnaire and semi-structured interview as reported in the previous chapter. They were "historical cases used by HOS students", "current issues used by SSI students", "knowing is seeing", "incomplete understanding of the role of subjectivity in science", "believing authority's claims" and "believing machine / technology".

5.6.1 Historical cases used by HOS students

These themes to a certain extent reveal students' more nuanced ideas about NOS beyond the score they obtained from the VNOS-D+ questionnaire. The study discovered that HOS students seemed to make more reference to historical cases as evidence to support their assertions or arguments across difference NOS tenets. This is evidenced by the examples that they used to explain their choices were distributed in Mendel's laws, the discovery of cell, and the discovery of vaccine. Students' ideas might be attributed to the course design for this treatment group as the historical cases those students cited were largely derived from the contents of the HOS lessons, in which they were provided with concrete historical episodes of how science actually works. The process of discovery of science knowledge by scientists might parallel the ways of students' thinking (Yip, 2006).

5.6.2 Current issues used by SSI students

For students in the SSI group, there seemed to be a greater tendency to use more recent issues or examples to substantiate their claims. They seemed to be more able to give more examples in explaining and describing the tenet of "*Theory & Law*", "*Tentativeness*" and "*Social & cultural embeddedness*" than students in the HOS group. For instance, many of them used SARS, Dengue fever, and Avian flu as examples to explain their responses. Comparatively speaking, fewer HOS students made use of examples from the intervention, such as the invention of vaccine, to substantiate their claim. This finding that the SSI teaching approach may benefit students in learning the nature of science by inducing them to use examples related to SSIs to support their views about NOS ideas is consistent with other research studies (Eastwood et al., 2012; Schalk, 2012; Walker & Ziedler, 2007). By contrast, there were fewer students from the HOS group that drew examples from their prior learning, such as the heliocentric theory.

The reason for the difference between the two groups may be that SSI lessons provided students with more opportunities to discuss how current issues have influenced the development of scientific knowledge. An example is the topic of Dengue fever, in which students learned how the disease might have spread from one place to another. They discovered about mosquitoes as the carrier of that virus, the life cycle of mosquitoes, how far the mosquitoes can fly, so on and so forth. They then discussed in groups by considering all the information they had acquired to decide how to stop the spread of the disease. They had come to the understanding that the discovery of the life cycle of mosquitoes was by observation. They also knew that they needed to test their hypothesis before they could inform the public about the way to stop the spreading of the disease, that is, they needed to obtain relevant empirical evidence. In addition, it was natural for students to relate scientific research on dengue fever to what was happening to society at that time, recognizing that it was an issue of public health that might affect every single citizen. The influences of the treatment or course design on the findings were further discussed in the next section.

The above finding about the impact of the SSI approach on students' argumentation about NOS is consistent with the findings of Eastwood et al. (2012). They found that grade 11 and 12 students were able to develop the concept of NOS after an SSI-oriented intervention. They also found that students were able to use examples to describe and explain the *social and cultural embedded* tenet of NOS. The findings in this study also concur with the findings of Walker & Ziedler (2007). The two researchers used SSI as the stem in the debate to deliver the concept of NOS to students. In the intervention process, the researchers did not identify the manifestation of any tenets of NOS during the debate in the class, but students showed the skill of using evidence to prove or explain NOS when responding to the questionnaire after the intervention.

Furthermore, as shown by the interview data, students in the SSI group tended to give more examples to support their choices, including those they obtained from previous learning in science and biology classes, in addition to those that they had learnt from the intervention. The examples they cited included the shape of the earth, and the theory of evolution.

Overall, the results showed that SSI students were generally more able to give examples to support their claims than their counterparts in the HOS group. This finding is in alignment with the finding of Walker & Ziedler (2007) that students using an SSI approach were able to use evidence to explain their choices after the intervention. Hence, one of the advantages of using SSI to teach NOS is to reinforce students' use of evidence and examples to justify their decisions.

In summary, the tendency of HOS students giving historical cases as examples, and SSI students using current issues as supporting evidence seem to be inherent of the curriculum design. This implies that both teaching approaches have their own strengths and weaknesses in delivering NOS.

5.6.3 Knowing is seeing

From the qualitative data of the questionnaire and interview, it was found that some students possessed the concept that could be characterized as "knowing is seeing". As Khishfe (2008) mentioned that students possessing this concept might reject the tenet of *creativity and imagination* as a component of NOS. Although quantitative analysis showed that students in both treatment groups had achieved statistically significant improvement in the tenet of *creativity and imagination*, results of qualitative analysis of the questionnaire did reveal students in both groups possessed the concept of "knowing is seeing', for example, when they referred to the appearance of dinosaur and the internal structure of the earth. Overall, there were more than half of the students holding this view, this conception was also supported by the interview findings where students made similar claims in that they only believed the science knowledge as truth only by seeing that it happened.

Regarding the performance of the two treatment groups, more HOS students possessed the idea of "knowing is seeing" than SSI students. Yip (2006) suggested that this might be associated with the course design based on the HOS approach, which by default relied on concrete examples drawn from historical stories to reflect how science actually works. So, it is possible to infer that students might perceive science as a body of observable knowledge aggregated over the historical period.

5.6.4 Incomplete understanding of the role of subjectivity in science

For the questionnaire, it appears that some students in both groups did not have a complete understanding of the role played by subjectivity in the development of science. These students generally considered that science is subjective as different scientists might have their own views in asking questions, approaching their question in different ways, and drawing different conclusions from their own perspectives. However, they did not seem to grasp the idea that while subjectivity is inherent to scientific inquiry particularly at the initial stage, yet, the very aim of the whole scientific inquiry process is to search for evidence-based objective evidence as far as possible for building science knowledge that could be trusted, and hence minimizing the degree of subjectivity. That is to say, even though scientists may start with contradictory hypotheses or research methods that they subjectively chose, it is highly possible that they would come to similar conclusions, leading to the construction of more objective knowledge.

As mentioned previously, students had achieved only a low understanding of all tenets in the pre-test, particularly the tenet of subjectivity, which is the lowest as shown by the pre-test and post-test results for both intervention groups. The reason for the poor results in the pre-test may be that the students had not learned this tenet in the curriculum at junior levels. This echoes Abd-El-Khalick and Lederman's (2000) finding that pre-learning knowledge of students about NOS was insufficient prior to intervention. Hence, it seems to be common for students to possess weak concepts of NOS prior to intervention. Moreover, the finding of the qualitative analysis indicated that almost a quarter of students from both groups possessed incomplete understanding of the role of subjectivity in science. Although both teaching methods touched on the tenet of subjectivity, and the students also showed improvement after intervention as reflected by the paired *t*-test, their learning of subjectivity still appeared to be less than desirable no matter which approach was used. This is evidenced by the findings that students could not think like scientists in generating different conclusions or hypotheses from the same set of data about the way of disease transmission for the SSI group, and about the three dimensional structure of DNA for the HOS group.

Students' incomplete view of the nature of subjectivity in science may be stemmed from weaknesses in the course design for both treatment groups. In the HOS intervention, the notion of subjectivity was included in the second lesson with regard to the prediction of the structure of DNA by different scientists during 1950s. The students were told about the process of DNA structure discovery by different scientists based on the same set of data about DNA, and that it might be the different knowledge background of the scientists that had led them to generate the structure of DNA in a different way. However, students did not seem to possess the necessary knowledge background to appreciate the influence of subjectivity. In the SSI intervention, an activity was designed to divide students into two groups to discuss the trend of the outbreak of Dengue fever in Hong Kong, and the two groups are expected to come up with their own conclusion or hypotheses. Even so, they could not generate different conclusion based on different interpretation of the data. This might again be attributed to the students' lack of scientific knowledge about the spread of disease to display different mindsets characteristic of scientists. This might have prevented students from experiencing the subjectivity tenet of NOS. This implies that more effort has to be made to enhance students' understanding of this NOS tenet. The implication of this finding was discussed further in the final chapter on implications of this study.

5.6.5 Believing in authority's claims

From the findings of the semi-structured interview and questionnaire, it was found that some students in both groups displayed the concept of believing in authority's claim, which is consistent with the finding of Bråten et al. (2011). Textbooks, magazines, library books, teachers and scientists were all regarded as authoritative source of science knowledge. Such belief in authority is evidenced by the oft-cited statement made by the interviewees toward the end of the interview that "it (this knowledge) is told by the textbook".

The reason may be attributed to the common classroom practice of teaching students to believe the knowledge in the printed books during their schooling, without learning how to question theories transmitted by the textbooks. As Bråten et al. (2011) mentioned that even for undergraduates, they would treat the information from textbooks as reliable and trustworthy. It was because they had learned to believe the textbook as a very important authority for imparting knowledge when they were at school.

In summary, the results obtained from the quantitative analysis showed that there was no statistically significant difference between the two teaching approaches in students learning of NOS. However, there were some fine characteristics of and differences in students' thoughts about NOS and the ways the two treatment groups supported their assertions as revealed by more detailed qualitative analysis of the student responses in the post-test questionnaire.

5.6.6 Believing in machine / technology

The qualitative data also shows that more students from the HOS group expressed the tendency of believing that technology has played a vital role in scientific development than the SSI group. This was probably due to the more explicit and noticeable role of technology in the development of science throughout the developmental history of science. The historical perspective and the evidence revealed from such perspective, such as the discovery of cell with the invention of the microscope, might have provided the idea for such view. This echoes the tenet of tentativeness as students learned to believe that technology played an important role in scientific development. Students' performance in this tenet was very good in the post-test in both the HOS and SSI groups. This may be the reason why the junior curriculum design was using historically based science stories as the teaching method in delivering science concepts, so that students could learn that scientific knowledge is changeable, due to technology advancement.

Overall, from the student's responses to the questionnaire and interview, students generally were able to provide their answer in terms of whether they agree or disagree with a claim, However, the majority only gave very short answers without elaborating or explaining their answer in detail. For example, the question about tentativeness of science asked how "s*cientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example."* Students in general gave short answers such as "believe" or "agree to change in future", without explaining further or providing relevant illustrations. For some who could provide examples, they just provided one or two keywords, for example, heliocentrism, without explaining how and why people changed their views. Students did not go further to explain that due to technology advancement like the production of telescope, scientists were able to observe the universe and collect more evidence to overturn the old theory of geocentrism. The reason why students were unable to provide more detailed explanation might be that they did not know very clearly the story behind that term. Hence, they were unable to give a clear description of the theory of heliocentrism. The same problem was also observed in other examples raised by the students such as the discovery of the spherical shape of the earth, the discovery of vaccine, and the discovery of cell, Mendel's laws, and Newton's law.

It is noteworthy that most of the students from both groups believed that science would change in future, since we are now living in a society that have seen great technological advancement. For instance, they experienced the increased bandwidth of wireless communication from 2G to 5G, and new inventions appear almost every day. For the SSI students, they could provide examples to support and support their answer by citing arguments such as: 1) ancient scholars believed that the shape of the earth was flat, but it was turned down by new discoveries; 2) doctors believed that gastric ulcer was not caused by bacteria, since those bacteria could not possibly survive in the acidic stomach, but it was turned down by the discovery of Helicobacter surviving in the stomach; 3) people did not know the cell is the basic unit of an organism until the microscope was invented; and 4) the rate of death was reduced by the discovery of vaccination.

Although the performance of both groups was not satisfactory in terms of elaborating claims with scientific evidence, the SSI group seemed to have done better than the HOS group in this respect. For the HOS students, it seemed that they could support their answer with only limited examples and elaboration, and most of them only provided such answer as, "I believe it would change", without further elaboration or examples for illustration. It is worthy of noting that some of the students from the SSI group were able to give examples of a fairly wide range, such as vaccination discovery, medical technology advancement to treat cancer, parental identification by DNA fingerprinting, bacteria in stomach and the discovery of cells. This may be due to the lesson design typical of the SSI lesson, which involves relatively wide range of issues for students to discuss. Students therefore needed to raise relevant evidence to support their claims during the discussion. Through this process, they might have steadily built up an ability of using evidence and examples to explain their claim or decision (Walker & Ziedler, 2007).

As reflected by the students' response to the other questions, both of the treatment groups were able to make use of vaccination to explain that scientific knowledge would change, implying "*tentativeness*". This is presumably because the students had already completed the topic of body defense in regular biology lesson, from which they learnt the experiment of Edward Jenner and how he discovered vaccination to treat the disease of smallpox, therefore some of the students in both groups were able to apply that knowledge in their response to the questionnaire. Similarly, the students were able to use "bacteria in stomach" and "cell discovery" as examples to elaborate on the idea of tentativeness. In summary, a relative high percentage of students from both groups were able to use examples derived from their previous learning experiences.

For students' performance in the tenet of *social & cultural embedded*, more students in the SSI group were able to support their answer with examples and evidence than the HOS group. The reason might be due to the content of the SSI being related to current issues; therefore, students might have developed the necessary skills in using current issues to provide suitable examples to explain science phenomena. Comparatively speaking, the HOS approach seemed not to be as effective as the SSI approach in developing students' understanding of this tenet. This finding is consistent with the literature that the HOS approach might be more effective in assisting students in developing understanding of the *empirical basis*, *observation & inference*, *creativity & imagination* tenets, but less effective for the *social & cultural embedded* tenet (Abd-El-Khalick & Lederman, 2000; Fouad, Masters & Akerson, 2015).

5.7 Factors mediating the impact of the teaching approaches for NOS learning

5.7.1 Biology achievement

This study also explores other potential factors that might affect students learning of NOS, such as biology achievement and gender. According to findings of the 2-way ANCOVA, there was no statistically significant interaction between biology academic performance and two teaching approaches of HOS or SSI in improving students learning of all tenets of NOS. However, according to the Pearson's correlation, there was statistically significant difference in the tenet of theories & laws and biology achievement for the HOS group only. This might be taken to imply that students with higher biology achievement would learn the tenet of theories & laws better when the HOS approach was employed. However, the SSI group did not show such a significant relationship. While the reason behind remains to be explored, it might be that higher achievers were more capable of studying historical materials through the HOS approach, which posed a greater demand on students in identifying relevant concepts including theories and laws, and applying more complex reasoning skills to understand the relationship of these concepts. This inference echoes the explanation offered by Tsai (1998) that high achievers may exhibit a higher connectedness of their thoughts. However, such cognitive tasks may be too challenging for lower achievers in general. This finding may cast doubts about the suitability of the HOS approach for low achievers in biology.

5.7.2 Association between gender and teaching approaches

As to the relationship between gender and the teaching approaches, there was no statistically significant interaction between the two for all the seven tenets of NOS according to the findings of the two-way ANCOVA. This lack of significant difference between the two genders in learning NOS is consistent with the findings of Dogan & Abd-El-Khalick (2008) and Liu & Tsai (2008), who reported similar results in their studies. However, the present findings do not seem to support the findings from other researchers (Tsai, 2006; Tsai & Liu, 2005; Huang et al., 2005), who reported male students learning NOS better than female students.

5.8 Conclusion

For RQ 1, “Could the SSI and HOS teaching approaches enhance Hong Kong senior secondary students’ understanding of major tenets of NOS?”, it will be discussed in following paragraph.

It was found that HOS was the effective teaching approach in improving Hong Kong students in learning all the seven tenets of NOS, especially in three tenets - *creativity & imagination*, *observation & inference* and *social & cultural embedded*. The reason may be that the historical cases in the HOS course could provide students with concrete episodes of how scientist works in discovering scientific knowledge (Yip, 2006), the development of scientific knowledge as affected by society, and of scientists using their observation and imagination. Moreover, the tenet of *observation & inference* was correlated with the tenets of *social & cultural embedded,* and *subjectivity*, so that if students learn one tenet of NOS better, there would be corresponding improvement in learning the other tenet.

Additionally, it was found that the SSI approach was also effective in improving Hong Kong students’ learning of all tenets of NOS, especially the tenets of *creativity & imagination* and *social & cultural embedded*. It may be the curriculum design that allowed them to experience the influence of the social and cultural factors on scientific development, which also involved creativity and imagination. Moreover, the tenet of *observation & inference* was also correlated with the tenet of *social & cultural embedded*.

Both teaching methods saw statistically significant difference in improving both groups of students in learning all tenets of NOS. There seemed to be greater improvement in the tenets of *creativity & imagination* and *social & cultural embeddedness* for both HOS and SSI groups.

The improvement in students' understanding of *creativity and imagination* is particularly noteworthy. This is because according to the finding by Khishfe (2008), students seemed to reject the tenet of *creativity & imagination* as a component of nature of science, since they are impeded by the idea of "knowing is seeing". This relative wide scope of improvement for both treatment groups might be related to the curriculum design specially tailored to teaching students to understand NOS through either the HOS or the SSI approach. For example, the historical episode of Edward Jenner's producing vaccine against smallpox based on his observation that milkmaids infected with cowpox were seemingly immune to smallpox reflects the tenet of creativity and imagination. For the SSI approach, the concept of creativity and imagination was imparted to the students via the topic of Human Genome Project, which led them to think about the prospect of treating hereditary diseases by the creative manipulation of genes.

For RQ2, "Which approach, SSI or HOS, is more effective in helping Senior Secondary Biology students develop informed conceptions of the major NOS tenets?" There was no statistically significant difference between the two teaching methods in improving students learning of NOS, but it was found from the qualitative analysis of post-test questionnaire and the interview that the SSI students were more able to use examples, drawing either from the intervention or previous science lessons to explain and support their assertions than HOS students.

For RQ3, "Are there any influences of gender or biology performance on the students' learning of NOS using either approach?". There were no gender differences in the learning of NOS using either approach. There was no significant difference between higher achievers and lower achievers in the learning of NOS using either approach. Despite this, it was found that higher achievers learnt better with regard to the tenet of *theory & law* in the HOS group.

The findings of this study discovered that all participants had poor understanding of the seven NOS tenets as shown by their low score in pre-test. There were several possible factors that contributed to this outcome. The first is the teaching factor. Hong Kong teachers did not learn about the NOS during their schooling (Wong et al., 2011), so they may not be familiar with the concepts of NOS, hence they may not be competent in teaching those concepts to students. As the teacher depended heavily on textbook contents to deliver the lesson to students, so for contents that did not appear in the textbook, those knowledge or content might be skipped (Yip, 2006).

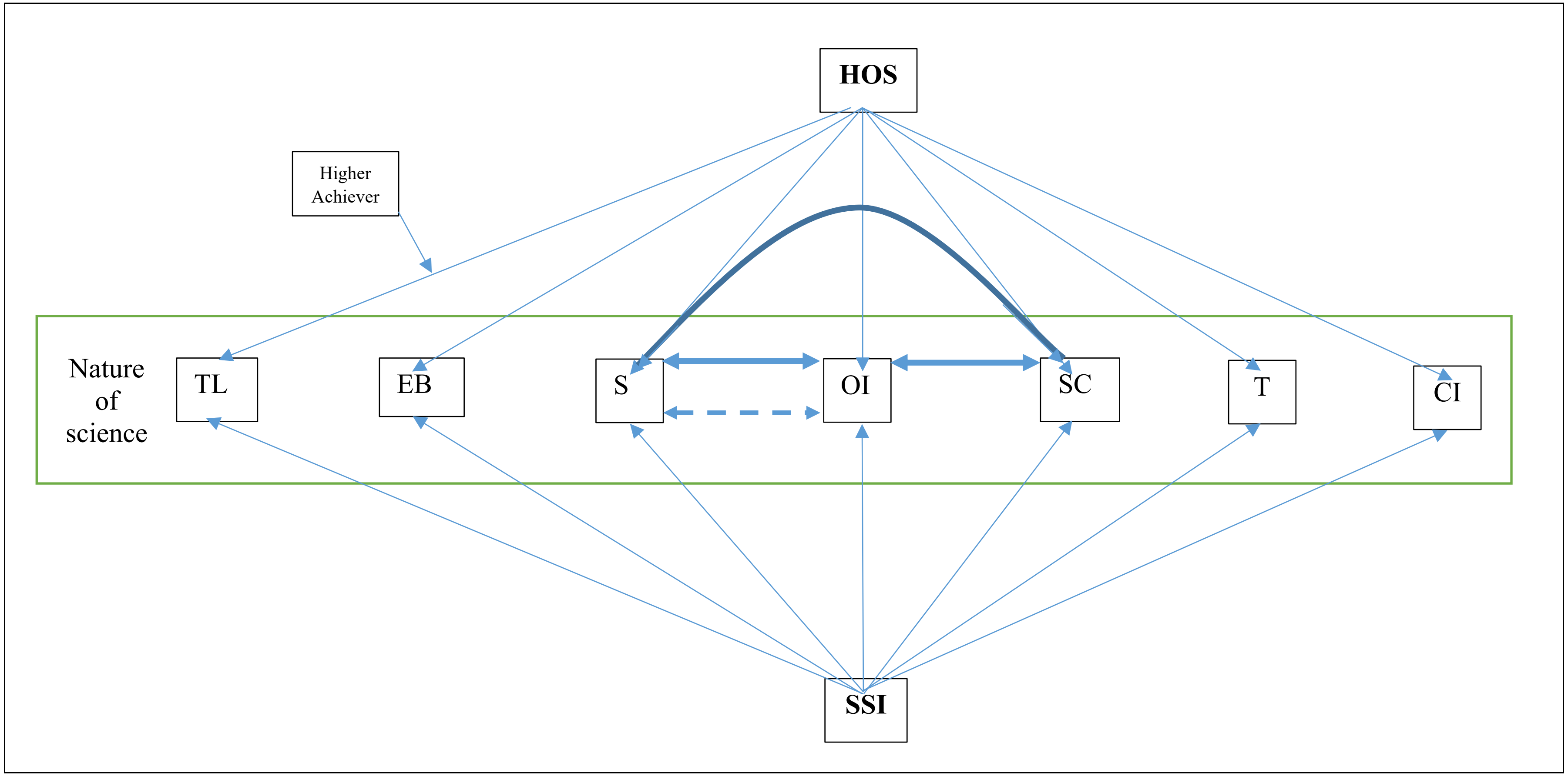
The second is the learning factor. Textbook is the main vehicle to deliver knowledge to students according to the systematic reviews of the two Hong Kong two junior science textbooks and two senior secondary biology textbooks in chapter 4. It was found that most of the textbooks pointed out the concepts or ideas of NOS hidden in the historical stories implicitly, and no concepts of NOS were printed explicitly on the textbooks. As the students tended to treat the information from textbook as reliable and trustworthy, they have learned to believe the textbooks as a very important authority during their schooling (Braten et al., 2011). As there were no concepts of NOS in the textbook, so students could not learn the concepts of NOS through self-study. The third factor is the assessment factor. Since NOS represents only a very small proportion of the areas to be assessed by the HKDSE examination as mentioned in Chapter one, teachers would rather spend more time and effort on those materials need to be tested in examination to help students attain better overall result (Lederman, 2007). As a result, those knowledge related to NOS may be skipped, thus depriving students of the chances of learning NOS.

In order to improve learning of NOS by senior secondary biology students, an alternative teaching approach using SSI was trialed for comparison with the existing teaching approach. According to quantitative statistic result, both teaching approaches were able to improve students learning of NOS with statistically significant difference outcomes. However, when the results of both approaches were compared, no statistically significant difference results were obtained. Hence, one cannot claim which teaching approach is the better teaching approach for NOS learning. However, based on the qualitative results obtained from the questionnaire and student interviews, it was discovered that the SSI group could use more examples to describe and explain their claims about such tenets as “tentativeness” and “society and cultural embeddedness” with the use of recent issues or examples. By contrast, the HOS students appeared to be more able to use examples of historical cases to explain their claims. Hence, it may be worthy of exploring the potential of using both teaching approaches simultaneously to deliver NOS to students. This will hopefully capitalize on the strengths of both approaches, thereby generating a synergetic effect.

According to the findings of this study, the proposed theoretical framework was amended as in Figure 4. Both teaching approaches were found to have improved senior secondary biology students in learning the seven tenets of NOS effectively, even though the magnitudes of the gain in scores among them were different. Also, for the HOS group, positive correlation was found between the tenets of, *subjectivity and, observation & inference*, and between *subjectivity* and *social & cultural embedded*. Whereas, for the SSI group, there was positive correlation between *subjectivity* and *observation & inference*. When the HOS teaching approach was applied to higher achievers in biology, it could produce greater improvement in the tenet of *Theory & Law*.

Additionally, more insights into the students' understanding of NOS were identified from the qualitative data analysis. Several themes were found to be embedded in students' understanding of NOS, including "Knowing is seeing", "incomplete understanding of the role of subjectivity in science development", and "Believing in technology". They might have exerted various influences in the students' learning of NOS. However, these influences cannot be confirmed by this study, and further studies are required.

Figure 4 Modified theoretical framework



Keys:
TL: Theory & Law; EB: Empirical Basis; S: Subjectivity; OI: Observation & Inference; SC: Social & Cultural embedded; T: Tentativeness; CI: Creativity & Imagination
Solid arrow line: positive influence; Solid bi-directional arrow line: positive association between tenets in HOS; Dotted bi-directional arrow line: positive association between tenets in SSI.

6 Implications and Recommendations

6.1 Limitation of intervention

There are a number of limitations to this research study, most of which could be attributed to the limitation of myself as the sole researcher who needed to undertake full-time teaching and administrative duties at the same time. There were three major limitations. First, the sample size was too small, which might adversely affect the generalizability of this research. Since the study had to be restricted to four classes within same school setting, there were only 67 students in total to participate the study. There were only total of 41 students remaining until the end of the intervention process. It might be the result of the intervention held during the extra lesson periods in the summer vacation. If it were organized during the regular school day, it may reduce the number of students skipping the lessons and increase the number of students who could complete the intervention.

Second, due to heavy teaching schedule, the intervention had to be conducted during the period of summer vacation. As a result, the intervention period was compressed into several consecutive days, so the length of intervention might not be long enough to produce more reliable change. Since each of the six lessons undertaken lasted only 50-minute for 3 consecutive days, with two 50-minute lessons per day. It was rather intensive for the students to learn the concept of NOS regardless of whether it was conducted by the SSI or HOS approach. For deeper learning to take place, it is suggested to extend the lessons to 3 weeks, with a longer lesson for each week. It is hoped that students could deepen their learning and better consolidate the knowledge gained.

Third, due to the relative short length of intervention, the time between the pre-test and post-test were quite short. It may be better to arrange the post-test to take place within a longer time after the pre-test. This hopefully could better assess students' real improvement in their understanding of NOS to remove any effect of memorization as far as possible. This may also help to better differentiate the effects of the two teaching approaches and see which approach could achieve a more long-lasting effect. In order to gain the more reliable result, it is suggested to conduct the post-test within three weeks or longer after the end of the intervention. According to Fleming & Alexander (2001), delayed post-test can be used to evaluate the retention ability of students in the knowledge over a relatively long period of time after their learning, and delayed post-test is even suggested after 6 months of the intervention. This could test the effectiveness of the teaching methods in producing deeper understanding in the mind of students.

Insights into the problems of NOS education in Hong Kong schools

As reflected from the findings of this study, there were a number of possible reasons causing students to obtain poor results in the HKDSE. In light of the present study design, which yielded positive learning outcomes for the HOS group, the most probable reason to account for the poor results of the HKDSE in the area of NOS is inadequate teaching and/or instructional design. As informed by the HKDSE examination reports, the majority of the candidates seemed to have no ideas about the NOS. Many of them only revised the previous examination papers for the concepts of NOS and gave the same answer as required by the previous examinations (HKEAA, 2016; HKEAA, 2017). This put into question whether the candidates have achieved any effective understanding of NOS, even though they were hardworking in their revision of

NOS. Thus, the reports highly recommended that the teachers use the teaching material pack produced by the Education Bureau to improve students in learning NOS.

It is difficult to compare students' performance in this study and the HKDSE candidates' performance as the test items used were entirely different, so is the context in which students were assessed. Despite this, the findings cast doubts about the effectiveness of NOS teaching in the present biology curriculum. Moreover, there may be some hidden causes underlying the problems stated in the examination reports.

First, as teaching in Hong Kong schools are essentially textbook-based, which means that the teaching contents, and the way that these contents are taught are highly dependent on the textbook (Yip, 2006). Students also tend to rely on previous examination papers as a guide to their revision of NOS contents (HKEAA, 2016; HKEAA, 2017). However, explicit contents of NOS were largely absent from current textbooks. Most textbooks were revised after the new curriculum has been launched with the concepts of NOS incorporated into the syllabus for junior and senior secondary science subjects. However, teachers mostly employ an implicit way to deliver the concepts of NOS embedded in historical stories about how the scientists works. No clear definitions of NOS tenets were printed or elaborated in the student's version of the textbook. Relevant contents and instructions on NOS are only printed in the teacher's textbook with teaching notes for the teacher only. Such ways of delivery of NOS was clearly not explicit enough for effective teaching of NOS. If the concepts of NOS were printed in the student's textbook, students might have learnt those concepts of NOS at least through self-study, or as a revision guide before any examination or test. As Yip (2006) mentioned that teachers depended heavily on the textbook content to deliver the lesson to students, therefore if the knowledge or content did not appear in the textbook, they might be skipped. That was perhaps the reason why students only used previous examination papers as the revision materials.

Second, the teaching strategy of teachers may focus on the content knowledge of the biology rather than the nature of science. This is because NOS only takes up a very small weighting in the whole examination paper, which is from 1.25% to 2.5%, and the rest of the marks were allocated to biology content knowledge. In light of this, it is conceivable that teachers prefer to spend more time to describe and explain the subject content rather than NOS. Students may also treat the biology content knowledge as more important than the concept of NOS, since they are well aware of the small contribution of NOS to the whole assessment, and consequently to the total score. This echoes Lederman's (2007) argument that teachers would rather spend more time and effort on those materials need to be tested in examination for students to attain better result.

Third, Hong Kong teachers had seldom been taught about the concepts of NOS when they were school students, so they had no ideas about NOS and did not know how to teach the concepts of NOS to students effectively. Although appropriate teacher training was launched just after the implementation of the new curriculum, such training was held only for a very short period of time for in-service teachers, and not necessarily embedded in the initial teacher training program as a compulsory part. Moreover, their attitudes toward teaching NOS in normal lessons is also questionable (Wong et al., 2011).

6.2 Implications for Biology curriculum development

In view of the implicit teaching approach adopted by the textbooks as explained in the previous section, which is not accompanied by comprehensive descriptions and explanations about the concepts of NOS, it is suggested that the on-going review of new textbooks be strengthened with particular reference to the contents about the nature of science before placing particular textbooks on the recommended list for schools or teachers. The curriculum planners of the education authority may recommend or even require textbook publishers include the concepts of NOS explicitly in the content of the textbook, preferably setting aside a chapter discussing the concepts of NOS, with relevant scenarios and guiding questions to stimulate discussion and facilitate students to apply those concepts. As Bergqvist & Chang Rundgren (2017) found that teachers treated the textbooks as important resources for preparing their lessons and teaching, it is important for biology textbooks to include an explicit discussion on NOS for students to learn NOS more effectively. Although, according to the HKEAA examination report, teachers were recommended to use the teaching materials specially designed by the Science Section of Education Bureau for teaching the NOS to senior secondary science students during the lesson, the advice by Yip (2006) should be heeded that since teachers depended heavily on the textbook content to deliver the lesson to students, if such content does not appear in the textbook, it might be skipped. In light of this, it is recommended the EDB grants the copyright of the teaching packages they produced to the publishers so that publishers could adopt these contents into their textbooks as a means to enrich textbook coverage of NOS concepts.

6.3 Implications for Instructional practices

According to the findings of this study, which showed that both teaching approaches were able to achieve comparable results in improving students' understanding of the concepts of NOS. It is suggested teachers adopt either HOS or SSI as the teaching approach based on the familiarity of the teachers with these two approaches. If the teacher is familiar with the history of science with a variety of science stories at his or her disposal, it would be ideal for them to use the HOS approach. This is because these teachers should be more capable of facilitating students to learn by using historical cases to bring out the idea of different NOS tenets. The historical stories that could be used are extremely diverse such as those about the theory of evolution, Newton's law, the shape of the earth, heliocentric, discovery of cell, law of gravity, and DNA parentage testing. The advantage of the HOS approach is that students could make use of these historical cases to identify concrete episodes that reflect how science actually works. The historical development of science might parallel the ways of students' thinking, providing mental challenges to students for appreciating the evolution and revolution of the scientific knowledge (Yip, 2006).

If the teacher is familiar or interested in keeping themselves updated on socio-scientific issues from news, he or she would be at an advantageous position to infuse relevant SSIs into the teaching process. According to the result of qualitative analysis, it was found that students learning through the SSI teaching approach were better able to use examples to prove and explain the answer as supported by Walker & Zeidler (2007). Moreover, Christenson & Chang Rundgren (2015) suggested that SSI-based teaching and learning could include classroom debate. The present study found out that during the intervention, students' talk appeared to be more frequent in the SSI class than the HOS class. Hence, the SSI approach is conducive to increased participation by students in the discussion, which is beneficial for their learning. Moreover, classroom debate requires higher order of thinking, which is well valued in science education.

However, for academically more able students, it may be more fruitful to use HOS teaching approach, since this study seemed to suggest that HOS was able to improve higher achievers in learning the tenet of scientific theories and scientific laws. Despite this, it was found that more students from the HOS group believed in scientific knowledge by seeing, which may lead to the rejection of the tenet of creativity and imagination. Hence, it may not be advisable to use a singular teaching approach to deliver the NOS, but rather employing both approaches to deliver NOS in a synergistic and reciprocal manner to bridge the gaps of each approach, as well as catering for student diversity within a classroom.

In order to improve students learning the tenet of subjectivity of NOS, teachers are recommended to introduce the background of scientists to students with reference to the specialisms, of individual scientists, and the diversity of knowledge they may possess. This may help students appreciate how scientists derive their ideas in a subjective manner. That said, students should also be led to appreciate the arduous process experienced by scientists to support their subjective hypotheses with objective evidence such that their conclusions are beyond doubt and defensible.

In view of the lack of expertise in teaching NOS which is relatively new on the part of the teacher, it is suggested the concepts and pedagogy of NOS be included as a compulsory part in teacher training programs for all pre-service and in-service science teachers. Such knowledge about NOS includes what is NOS, how to teach NOS and how to apply the NOS in learning science. This is important because many teachers did not learn about the NOS when they attended school (Wong et al., 2011). Moreover, Education Bureau should also keep providing relevant in-service training courses for teachers to learn the pedagogy of teaching NOS, until improvement in HKDSE could be seen.

6.4 Implications for Assessment of students' achievement in NOS

It is suggested that the assessment of NOS be emphasized to a greater extent and strengthened in both breadth and depth. The learning outcomes with respect to the NOS should not be assessed only by summative assessment, but also by formative assessment. First, it is better to increase the weighting of NOS in summative assessment, particularly in such high-stake assessment as the HKDSE in order to raise the 'status' of NOS in the science curriculum. This is especially true as NOS now occupies only a very low proportion of teaching contents and teaching time in the syllabus and examination. Lederman (2007) has already pointed out that teachers would rather spend more time and effort on those contents that need to be tested in examination so that students could attain better result. If the weighting for NOS in the examination is increased, it may encourage teachers to focus teaching on the concept of NOS, thereby increasing the chance for students to be exposed to NOS. Second, it is suggested the number of assessments be increased during the learning process using different formats, in addition to written examinations. The concept of NOS could be taught in diverse ways, for example, through classroom debates & discussion, project learning, and practical tasks or non-practical tasks so as to enhance the effectiveness of NOS learning as well as to provide opportunities for teachers to assess students learning and application of NOS formatively.

6.5 Recommendations for Future Research

Although it was found from quantitative analysis that both HOS and SSI teaching approaches were able to contribute to and facilitate senior form biology students in Hong Kong in learning and understanding NOS with different magnitudes and effectiveness, the outcomes of qualitative analysis revealed more nuanced features about students' understanding of different NOS tenets after going through either of the two approaches. For instance, it was found that HOS students were more able to use historical cases as the evidence or reference to support their claim across different tenets, and SSI students were more able to use recent issues or examples to substantiate their claims. Research of larger scales, with bigger sample sizes and the use of different stories and issues, are needed to establish the validity of the present findings. Moreover, the application of HOS and SSI in biology can be expanded into other science subjects at both junior and senior levels to study the effect of other variables such as nature of the subject, and age, gender and academic performance of students. Furthermore, the simultaneous use of both approaches – HOS and SSI - is worthy of investigating to examine any synergistic effects created by combining the advantages intrinsic to each approach.

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8 Appendices

Appendix 1 – Pre-intervention VNOS questionnaire

Appendix 2 – Nature of science (Teacher’s notes)

Appendix 3 – Nature of science (Students’ worksheet)

Appendix 4A – History of science – Inheritance (Teacher’s notes)

Appendix 4B – History of science – Vaccination (Teacher’s notes)

Appendix 4C – History of science – DNA structure (Teacher’s notes)

Appendix 5A – History of science – Inheritance (Students’ worksheet)

Appendix 5B – History of science – Vaccination (Students’ worksheet)

Appendix 5C – History of science – DNA structure (Students’ worksheet)

Appendix 6A – Socio-scientific issues – Human Genome (Teacher’s notes)

Appendix 6B – Socio-scientific issues – Infectious diseases (Teacher’s notes)

Appendix 7A – Socio-scientific issues – Human Genome (Students’ worksheet)

Appendix 7B – Socio-scientific issues – Infectious diseases (Students’ worksheet)

Appendix 8 – Post-intervention VNOS questionnaire