A project entitled

Examining Hong Kong senior secondary and tertiary science students' epistemological view on the Nature of Science (NOS)

Submitted by

Hung Chun Man, Simon

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Declaration

I, *Hung Chun Man*, declare that this research report represents the own work under the supervision of professor Dr. Chong Yee Ling, and that it has not been submitted previously for examination to any tertiary institution.

Signed:

Hung Chun Man

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HUNG Chun Man

Abstract

This study examined and compared students' epistemological view on the Nature of Science (NOS) with 108 senior secondary science students and 96 tertiary education science students in Hong Kong using a quantitative method approach. Descriptive statistics, correlation test and one-way multivariate analysis (MANOVA) are applied to examine the data. Overall, students showed a mixed and independent epistemological view towards the NOS. Students who studied Biology as electives in HKDSE were observed to have significant effect on the view towards item "socio-cultural embeddedness" and "tentativeness", while significant effect of academic background can also be observed. Questions were aroused based on the result of Pearson Correlation test. Implication for the design of science lesson and limitation of research will also be discussed.

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Section 1: Introduction

Since the past few decades, there are trends of growing emphasis on teaching and learning Nature of Science (NOS) demonstrated by numerous educational and scientific studies. Researchers believe the enrichment of science students' NOS would be an indispensable component for improving students' scientific literacy (Lederman, 1992; Cheung, 2020). While considering NOS as one of the vital components of science educations, reforms in science education curricula have been made in many different countries. The objectives of nurturing students' understanding of NOS are being recorded in the educational documents published by the educational departments in those countries. (Eurydice Network, 2011; National Research Council, 2012).

However, researches and findings related to students' understanding of NOS are depressing. Lederman (1992) investigated the epistemological view of NOS possessed by students among different age groups and teachers. The result shows both students and teachers held inaccurate and inappropriate view of NOS regardless of methods or the instruments adopted in the investigation. Kang *et al*. (2004) further investigated the view of Korean students from different grades and discovered the majority of students possessed an absolutist perspective. Park *et al*. (2013) integrated views from different educators and listed a binary opposition of epistemology, where students either possessed realist or relativist view in NOS. The finding of Park *et al*. revealed students possessed contrasting view in some major concepts of NOS.

In the case of Hong Kong, it can be observed that the Education Bureau (EDB) and the Hong Kong Examination and Assessment Authority (HKEAA) also put emphasize on NOS, integrated NOS into senior secondary curriculum and assessment. Among various science subject, senior secondary Biology is the only subject which explicitly examine students' understanding of the NOS (HKEAA, 2015; Cheung, 2020). Yet, the academic results from Hong Kong Diploma of Secondary Education (HKDSE) biology examination parallel to the research findings of Lederman, Kang, and Park, where Hong Kong senior secondary biology students demonstrated an incomprehensive understanding on the content of NOS (HKEAA, 2012-2018).

Even though the importance of competent understanding of the NOS have been advocated throughout decades, science students or even teachers still hold a limited view towards NOS. Some studies suggested the reason that students, especially elementary-aged students, may hold a rather realist view because of the existence of constraints on abstract thinking based on the Piagetian developmental framework (Chandler, 1987; King & Kitchener, 1994). As students get older, the view of NOS was well assimilated into their mental structure and therefore resistant to change (Meichtry, 1992). In other words, students were keep holding the naïve view towards the NOS they possessed in their early age, without proper addressing and revising a more comprehensive framework of NOS in their secondary or even tertiary study. It is suspected that Hong Kong senior secondary science students happened to have a similar situation, and the contrasting ideas caused vague representation of NOS presented in the questions, leading to the poor academic results reported in HKDSE.

However, only few studies and researches were done regarding the epistemological view of NOS processed by Hong Kong students, and none of them are investigating cases of Hong Kong individually. Therefore, this research aims to:

[1] examine Hong Kong senior secondary and tertiary science students' epistemological views on the Nature of Science; and

[2] compare the epistemological view between Hong Kong senior secondary and tertiary science students.

Lacking sufficient empirical data on students' epistemological view on NOS directly results in the reduction of guidance and support for science teacher to design their lessons as well as providing instructions (Wan & Wong, 2016). Consequently, it will influence their teaching performance. Hopefully, this research could lay a more concrete foundation of Hong Kong science students' epistemological view on NOS and provide some insights for Hong Kong science teachers in their future teaching.

Section 2: Literature Review

2.1. Definition of Nature of Science (NOS)

The definition of Nature of Science (NOS) diverse among different scholars and science educators. As defined by Ryan & Aikenhead (1992), NOS is "*the understanding and appreciation of the nature of construction and validation of scientific knowledge, the work of scientists, processes of science, and sociology of science*", while Lederman (2007) argued NOS is "*the characteristics of scientific knowledge that are directly related to the way in which it is produced* " And Clough (2006) explained NOS as the study of understanding what science is, how science works, the epistemological and ontological foundation of science, the reciprocal role between science and society and how scientist interact with the society.

Despite the failure of reaching a consensus about the definition of NOS by scholars, the importance of advocating and nurturing our next generation about NOS was emphasized. Most researches investigating NOS have came to an agreement that studying NOS brings more benefits to the studying of science, such as (1) Enhancing the understanding of science itself and the process of science; (2) Helping to make more precise and comprehensive decision in socio-scientific issue and (3) Being more aware within the group of scientific community with more in-depth scientific content (Driver, et al, 1996; Donnelly, *et al*, 2011).

2.2. Framework of Nature of Science (NOS)

In spite of the advantage mentioned that are brought by the understanding of NOS, researchers nowadays could not arise a framework of NOS that are widely accepted by the majority. Various frameworks or approaches are being proposed by different researchers. Among all the frameworks and approaches of NOS-related investigation, two frameworks are more commonly seen and being presented, which are the “consensus view of NOS” as well as the “family resemblance approach (FRA)”.

Consensus view of NOS

Kampourakis (2016) explain the consensus view of NOS as the general conceptualization of NOS into several aspects. This framework is widely adopted by researchers to investigate the comprehensiveness of different development of science curricula related to NOS or other researchers associated with science education and practice (Ledermann, et al., 2002).

The elements included in a consensus list may varied depending on the research objectives raised by researchers. Yet, Erduran & Dagher (2014) traced different literatures related to the study of NOS recorded in these few decades, such as studies by Ledermann, et al. (2002), McComas (1998), and Abd-El-Khalick (2012) and concluded seven statements that are mostly characterized as the elements of NOS in a “consensus view”. The seven elements are included as (See also Appendix 1):

(1) The tentativeness nature of scientific knowledge

(2) Observation, Inference, and theoretical entities in science

(3) The theory-laden nature of scientific knowledge

(4) The creative and imaginative nature of scientific knowledge

(5) the social and cultural embeddedness of scientific knowledge

(6) Scientific theories and laws

(7) Myth of the scientific methods

Even though the “consensus view” of NOS becomes one of the major components in the empirical studies of science education, critiques could be found by some other researchers or educators. For instance, Grandy & Duschl (2007) argued the use of “consensus view” are “greatly oversimplify the nature of observation and theory and almost entirely ignores the role of models in the conceptual structure of science" (p.144). Yacoubian (2012) also opposed the use of consensus view as it is lacking clarity on how NOS ideas could be applied for various ends, lacking developmental trajectory for addressing NOS at different grade levels, and also distorting the process of the development of science. These researchers pointed out the limitation of using "consensus view" of NOS, where the oversimplification or distortion of NOS content cannot represent the whole picture of science, and may cause misunderstanding of science by future learners.

Despite the limitation mentioned, the use of "consensus view" in form of the common generalities of NOS could still be discovered in reform documents and international science education efforts presenting description of NOS. (Abd-El Khalick, 2012; Lederman et al., 2014).

Family resemblance approach (FRA)

While some researchers (Allchin, 2011; Clough, 2011; Elfin, *et al*. 1999; Wong & Hodson, 2009; Matthews, 2012) did not settle with conceptualizing NOS as statements, they justified that NOS should be applied to a boarder context, where students should also understand the process, institution and the socio-cultural context in which scientific knowledge is based on. It is declared that only by applying NOS in a boarder context could avoid students misunderstand that science is merely declarative in nature (Cheung, 2020).

In light of the dilemmas evoked by two groups of researchers, Erduran and Dagher (2014) proposed a more comprehensive framework named the Family Resemblance Approach (FRA). More emphasis are put on the philosophical position of the NOS in this framework, which allows scientists, educators, science teachers and students to reflect on the influence of different dimensions to science (See Appendix 2).

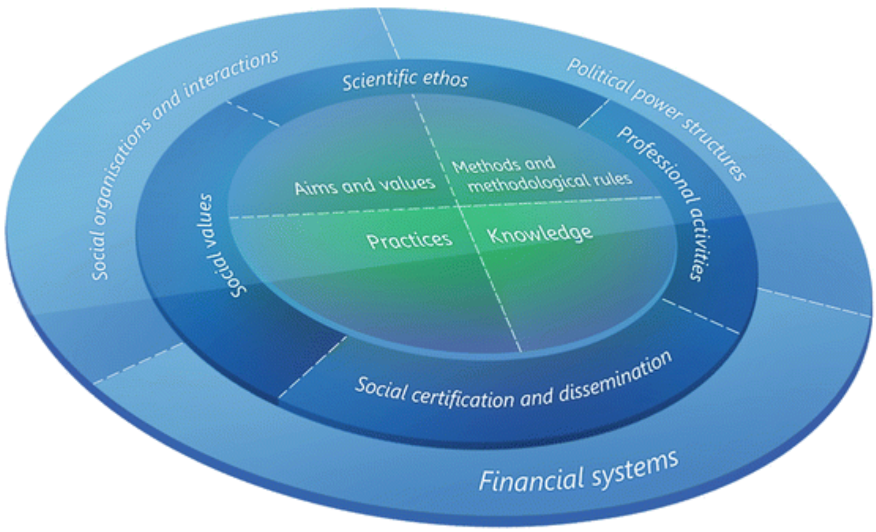

Figure 1. *FRA wheel (Eruduran & Dagher, 2014)*

The FRA included the "cognitive epistemic system" (containing aims and values, practices, knowledge, and method and methodological rules) and the "social institution system" (containing the social certification and dissemination, professional activities, scientific ethos and social values) which are first suggested by Irzik & Nola (2011). Based on the foundation of these two systems, Erduran & Dagher (2014) added the "financial system", "political power and structure" as well as the "social organization and interaction", which are three categories scientists considered as essential in scientific development. The comprehensive design of FRA wheel facilitates the design of teaching NOS, where students should first understand the epistemology of science (located in the centre of the wheel), and then being able to extend it to a broader social context, such as the influence of financial system, politics, and social organization, understanding how these factors shape the development of science (Cheung, 2020).

Regardless of the comprehensiveness shown in the FRA framework, it is not common to observe the use of FRA among science curricula. A rather simple or narrowed idea are more favoured by schools or educators to project NOS on their teaching. (Erduran & Dagher, 2014). Cheung (2020) examined the inclusion of NOS in HKDSE biology curriculum and assessment, and discover a particular emphasis on the cognitive-epistemic system (rather than the social institution system). Moreover, statements and terms such as "tentativeness", "social and cultural embedded" that are commonly included in the "consensus view" of NOS are found in the HKDSE assessment.

2.3. Philosophies of Nature of Science (NOS)

The content of NOS in science curricula depends on the epistemological orientation towards science in a large extent. There are various philosophical themes that explains what science is, what science is for, and how science is developed. From different literatures illustrating the philosophies on the NOS, two major philosophies could be identified, which are the universalism (or the realism) and the constructivism (or the relativism).

Matthew (1994) explained in his book that universalism presents science as a practice that cut across all cultures, races, gender, and religions. Universalists hold the perspective that any observation made in science are corresponding to the external reality, that the observation is absolutely objective, fixed and unchangeable (Milne & Taylor, 1998; Nussbaum, 1989; Roth, & Roychoudhury, 1994). In other words, scientists who hold the view of universalism consider science as an activity that is intellectual and goes beyond any differences between human and the society. Under universalism, some other branches of philosophies share the similar attributes. For example, scientists who process the view of logical positivism perceive statements as meaningful only when the statements are proven directly or indirectly through observation and experiment (Stumpf, 1966)

On the other hand, constructivist disagree the philosophies of universalism that scientific knowledge is objective and unchangeable. They argued the scientific knowledge learners acquired is built upon their own experience, in which they actively participate in the learning process and develop a deeper conceptual understanding of science. Therefore, the NOS should be subjective and the effect of human difference, such as the social, cultural and political aspects are significant (Park, Nielsen & Woodruff, 2014; Kang, Scharmann & Noh, 2004).

Apparently, universalism and constructivism illustrate distinct values towards the NOS. While students may also possess different epistemological view towards NOS, they will have distinct understanding or ideas towards various concepts of NOS. Park et al. (2014) traced researches and literatures and highlighted the contracting view on the NOS possessed by both the universalist and the constructivist (See Appendix 3).

For some researchers holding constructivist view, they considered the idea of universalism in terms of understanding the NOS as “naïve view” or “uninformed view”. (Ledermann *et al*., 2002; Liang *et al*., 2008; Stadermann & Goedhart, 2020). They believe teaching the next generation about the constructivist view of the NOS should be advocated in order to enhance the public scientific literacy.

Section 3: Methodology

This was a quantitative study of both senior secondary and tertiary science students' epistemological view on the NOS. Questionnaires were distributed and collected within 4 months (Nov 2021 – Feb 2022). The results collected from participants were investigated quantitively to study the possible impacts and correlations.

3.1 Participants

Participants in this research included 108 Hong Kong senior secondary students (aged from 16 – 18 years old) from 4 different local secondary schools and 96 Hong Kong tertiary education students (aged from 18 – 24 years old) using a convenience sampling procedure. Considering the selections of schools, no particular conditions (such as students' academic strength, school cultural and ethnic background) are taken into account in this research.

For students from senior secondary school, all students have taken at least one out of three science subjects (Biology, Physics and Chemistry) as one of their elective subjects in senior secondary education, and all of them have received compulsory education of integrated science in their junior secondary education (grade 7 – grade 9). For students from tertiary education, they either studied science electives in their secondary education, or received science-related courses provided in their tertiary institution. Therefore, it is assumed that all participants at least possessed some foundation content of science in their education.

While all participants received science education under the HKDSE curriculum, impacts of curriculum-related factors, such as the teaching content and assessment, are minimized and were not be considered in this research.

3.2 Development of instruments

A quantitative questionnaire was designed by taking reference and modified from other literatures which are also investigating the epistemological view of NOS (See Appendix 3) (Kang, *et al*., 2004; Chen, 2006; Liang, *et al*., 2008; Park, *et al*., 2014). The context of questionnaire is designed based on the seven components of NOS suggested by Chang, Chang and Tseng (2010). Total 6 constructs are included in the questionnaire, and each reflects one component of NOS, including (1) subjectivity (SUB); (2) Theories and Laws (LAWS); (3) Creativity and imagination (CRE); (4) Scientific research methods (METH); (5) socio-cultural embeddedness (CULT); and (6) Tentativeness (TEN). Total 23 statements are included in the questionnaire while each constructs contain 3 – 4 statements with either extreme universalist or constructivist view. Participants are asked to answer their opinion using 5-point Likert scales.

Meanwhile, a definition list, which included both Chinese and English definition of keywords appeared in the questionnaire, was attached with the questionnaire. The purpose of attaching the definition list was to prevent participants feeling unfamiliar with the wording used in the questionnaire or misinterpreting the statements.

3.3 Pilot test

Before the collection of data, the drafted questionnaire was distributed to 5 senior secondary school students and 5 tertiary education students for running the pilot test. The objective of the pilot test was to ensure the content fluency, and to check whether the use of words suits the reading level of participants. Comments are given by the students participated in the pilot test and modification of the questionnaire were done based on the comments.

3.4 Data Collection

The revised questionnaire was distributed to senior secondary science students in the period of Nov 2021 – Dec 2021, either in form of filling hardcopy questionnaire or filling online survey. Despite the differences of media, the content of questionnaire in both media were identical.

The period of distribution of questionnaire to tertiary education science students laid on Jan 2022 – Feb 2022. The majority of responses collected from tertiary education students were through online survey, as the deteriorating COVID-19 situation in Hong Kong limited the distribution of questionnaire in face-to-face mode.

3.5 Data analysis

The collected data was fully examined and participants' responses with unreliable answer were ignored before moving on to the analysis, assuring the credibility of the results and interpretation. To deal with the individual missing data, method of "mean substitution" presented by Roth & Switzer (1994) was applied in this research, in which the missing data will be replaced by the mean value of that particular statement. Followed with the "cleaning" procedure, reliability test is run on both 6 individual constructs and the overall survey. The Cronbach alpha value was obtained with the use of SPSS software.

All of the universalist statements are reversely coded to facilitate the consistency of data, so that universalist view will have low score, while constructivist view will have high score. Descriptive data, including mean value and S.D. was generated, providing basic information about the epistemological view Hong Kong science students possessed.

Correlation test between 6 NOS constructs and their sub-questions were done by checking the Pearson correlation coefficient in order to investigate the interdependency between various NOS constructs or between sub-questions.

The one-way multivariate analysis of variance (MANOVA) tested the effect of academic background and the subject background (whether students studied biology as one of their electives in HKDSE) on students' epistemological view on NOS. The statistical tool of Wilks's Lambda is used to check for the assumption of academic background and subject background effect. Univariate test using between-subjects tests were also performed to further investigate which statements or NOS concepts differ between academic background or subject background.

Section 4: Results and Discussion

A total of 204 responses are collected via filling of hard-copy questionnaire or online survey. After fully examining the responses from participants, 14 responses are filtered out as high repetition of same answer are found in these responses. It is assumed that these responses are stemmed from a lack of attention by certain participants, indicating a low response quality. Eventually, 190 effective responses are retained and kept for further analysis. Among the 190 responses, 103 participants were studying senior secondary, and 87 participants were studying tertiary education in terms of academic background. For the subject background, number of participants who studied biology in HKDSE and had no experience in studying biology are 109 and 81 respectively.

The overall Cronbach alpha for the entire questionnaire was calculated ($\alpha = 0.74$), indicating a high reliability and consistency of the result of the whole questionnaire. The Cronbach alpha value for each individual constructs are listed in Table 1. Specific attention is paid to the Cronbach alpha value of constructs "Theories and Laws" and "Scientific Research Methods" as their value are lower than 0.5. It is suggested that the low Cronbach alpha are possibly due to (1) vague and unclear statements; or (2) statements listed are not as extreme as other construct, leading to a low differentiation of epistemological view. In light of the high Cronbach alpha calculated for the entire questionnaire, the results of these two constructs are kept for analysis. Yet, special attention of results related to these two constructs have to be paid in the analysis afterwards.

The following analysis and discussion are presented in four parts: general epistemological view of students is presented first with the correlation test between constructs of the NOS. In the second section, the effect of subject (biology) background is presented, followed by the effect of academic background in the third section. Lastly, highlights from the correlation test of certain statements will be further investigated.

Table 1. *Cronbach alpha value for each NOS constructs*

NOS constructs	Cronbach alpha values
Subjectivity	0.508
Theories and Laws	0.458
Creativity and Imagination	0.579
Scientific Research Methods	0.484
Socio-cultural embeddedness	0.702
Tentativeness	0.706

4.1 General epistemological view of Hong Kong students

While all answers for statements with universalist view are reversely coded to confirm the consistency of scores, constructs with scores high than 3.00 was considered as having constructivist view while scores lower than 3.00 was considered as having universalist view. Across the whole data set (n=190), the highest mean was construct "tentativeness" (M_{TEN} = 3.95), and the lowest mean was "Theories and Laws" (M_{LAW} = 2.88). Table 2 illustrate the mean value and S.D for all 6 NOS constructs.

Apart from the descriptive data analysis of responses, a bivariate test was done to check whether interdependency could be observed between certain NOS constructs when participants were filling the questionnaire. In the correlation test done in SPSS software, the Pearson correlation coefficient (r-value) and the significance (p-value) were calculated (See Table 3). Even though some of the items were observed to have a low p-value ($p<0.05$), none of the r-values were significant to illustrate a high inter-correlation between constructs.

Table 2. *Mean value and S.D. for each NOS constructs*

NOS constructs	Mean values	S.D.
Subjectivity	3.15	0.73
Theories and Laws	2.88	0.60
Creativity and Imagination	3.57	0.77
Scientific Research Methods	2.89	0.38
Socio-cultural embeddedness	3.33	0.78
Tentativeness	3.95	0.66

Table 3. *Pearson correlation coefficient between responses of NOS constructs in questionnaire (p value >0.05 if not shown in the table)*

Constructs	SUB	LAWS	CRE	METH	CULT	TEN
SUB	1	r=0.105	0.0306	-0.011	0.026	-0.036
LAWS		1	0.051	0.17 (p=0.019)	0.189 (p=0.009)	0.000
CRE			1	-0.007	0.208 (p=0.004)	0.337 (p=0.000)
METH				1	0.093	-0.118
CULT					1	0.259 (p=0.000)
TEN						1

The mean values of each individual constructs indicated participants generally had a mixing view on the NOS. For constructs having higher scores ("Subjectivity", "Creativity and Imagination", "Socio-cultural embeddedness" and "Tentativeness"), it reflected a more constructivist view possessed by the participants. On the other hand, constructs having lower scores ("Theories and Laws", "Scientific Research Methods") reflected a more universalist view possessed by the participants. Meanwhile, the result of correlation test represents the absence of interdependency of participants when they are filling the questionnaire. This suggested that participants are actually considering each construct of NOS individually instead of considering NOS as a whole, and they did not follow one general philosophical background (either constructivism or universalism) during their consideration.

This finding corresponding to the study done by Park *et al*. (2014) investigated the epistemological view of students from different cultures on the NOS. They presented in their work that students were possessing different epistemologies regarding various NOS items. For example, when statements listed were related to the formation and development of scientific knowledge, students tend to stand in a constructivist view; Yet, when statements listed were emphasizing judgement content, students' responses were more universalist. Both results from Park *et al*. and this research revealed most students considered NOS or the process of scientific inquiry in a fragmentated manner. Even though they might present understanding of the NOS, they were not able to comprehend different constructs and acknowledge the intercorrelation between items (such as scientist required imagination and creativity to invent theories and laws, designing inquiry methods and interpret scientific data). Therefore, students did not fill in the questionnaire with one general philosophy, revealing a mixed epistemological view in the data analysis.

4.2 Effect of subject (biology) background

One-way MANOVAs using SPSS was used to examine the subject effect (whether students studied biology in HKDSE) on students' epistemological view of the NOS. We used Wilk's Lambda for multivariate test, showing variation of 0.82 – 0.99 at the degree of freedom (185). Table 4 shows the test results of the MANOVAs test in this section, and it indicates high significance only for constructs "socio-cultural embeddedness" and "tentativeness". Thus, follow-up univariate test is performed for these two constructs in order to check for the effect on specific statements.

Table 4. *Results of MANOVAs on effect of subjects (biology) and test of between-subject effect (n=190)*

	Multivariate test			Test between subject effect		
Constructs	Wilks Lambda	F	Sig (p-value)	Items	F	Sig (p-value)
Subjectivity	0.994	0.395	0.757	N/A		
Law and theories	0.987	0.620	0.649	N/A		
Creativity and imagination	0.984	0.771	0.545	N/A		
Scientific methods	0.990	0.446	0.775	N/A		
Socio-cultural embeddedness	0.947	2.571	0.039	CULT1	9.056	0.003
				CULT2	7.453	0.007
				CULT3	0.001	0.981
				CULT4	0.019	0.890
Tentativeness	0.822	10.035	0.000	TEN1	33.037	0.000
				TEN2	17.002	0.000
				TEN3	9.027	0.003
				TEN4	11.465	0.001

The subject (Biology) effect was significant for "socio-cultural embeddedness" as shown by the Wilks's Lambda value of 0.947 [F = 2.571, p<0.05]. The follow-up univariate test indicates two statements in this construct (CULT1 and CULT2, which are Q16 and Q17 in questionnaire respectively) are significantly different between two groups of participants. As both statements illustrated a universal and unbiased nature of science, regardless of the social and cultural impact, it is interpreted that students who have studied biology in HKDSE curriculum are more aware to the influences of social and cultural backgrounds to the actions and decisions made by scientists.

The subject (Biology) effect was also significant for "Tentativeness" as shown by the Wilks's Lambda value of 0.822 [F = 10.035, p<0.01]. And the follow-up univariate test indicates all statements included in this construct shows significant differences between two groups of participants. It is deduced that students who studied biology under

DSE curriculum have a better understanding of the tentative, dynamic nature of science, therefore holding a more constructivist view in answering the questions in this construct.

This result aligned with the curriculum and assessment design of the HKDSE, in which Biology is the only subject that explicitly assess students' understanding of the NOS. Cheung (2020) studied the inclusion of NOS in Hong Kong Biology assessment and curriculum, and he revealed the assessment authority used terminologies of NOS from the "consensus view". For instance, in 2013 DSE, students are advised to use statement "*science knowledge is tentative and dynamic*" to explain the contribution of Darwin and Jensen in the development of phototropism (HKEAA, 2013); And in 2014 DSE, students are asked to elaborate on the statement "*scientific knowledge is tentative and subject to change*" with the example of history discovering cell division (HKEAA, 2014).

Considering the inclusion of the NOS-related content in public exam, senior biology teachers therefore would teach students about the NOS in lesson explicitly, ensuring students are able to handle this type of questions. Various studies have revealed that the content of high-stake assessment (like HKDSE exam) will actually affect how and what science teacher teach, as well as affecting the designing of teaching and assessments in classroom (Brookhart, 2010; Eruduran *et al*., 2019b). Carey *et al.* (1989) also stated in their finding that the explicit addressing of the NOS could help students get a better understanding of it. Therefore, it is hypothesized that the understanding of NOS possessed by Hong Kong biology students will be reinforced because Hong Kong biology teacher will explicitly include NOS as one of the teaching contents in lesson and assessment, in order to equip students with NOS-related content to deal with public exam.

4.3 Effect of academic background

One-way MANOVAs using SPSS was used to examine the academic effect (either studying senior secondary or tertiary education) on students' epistemological view of the NOS. We used Wilk's Lambda for multivariate test, showing variation of 0.822 – 0.992 at the degree of freedom (185). Table 5 shows the test results of the MANOVAs test with academic background as the factor. "Law and theories", "Creativity and imagination", Scientific research method" and "socio-cultural embeddedness" shows high significant values, and follow-up univariate test is performed on the statements of these constructs to check for the academic effect on specific statements.

Table 5. *Results of MANOVAs on effect of academic background and test of between-subject effect (n=190)*

	Multivariate test			Test between-subject effect		
Constructs	Wilks Lambda	F	Sig (p-value)	Items	F	Sig (p-value)
Subjectivity	0.992	0.530	0.662	N/A		
Law and theories	0.912	4.477	0.002	LAW1	5.745	0.018
				LAW2	1.586	0.209
				LAW3	3.168	0.077
				LAW4	10.898	0.001
Creativity and imagination	0.822	10.033	0.000	CRE1	36.222	0.000
				CRE2	22.569	0.000
				CRE3	0.777	0.379
				CRE4	2.986	0.086
Scientific methods	0.888	5.829	0.000	METH1	5.909	0.016
				METH2	2.926	0.089
				METH3	4.574	0.034
				METH4	3.874	0.051
Socio-cultural embeddedness	0.898	5.226	0.001	CULT1	0.056	0.813
				CULT2	4.711	0.031
				CULT3	13.018	0.000
				CULT4	8.927	0.003
Tentativeness	0.992	0.373	0.828	N/A		

The MANOVA results for both "law and theories", "creativity and imagination", "scientific research methods", and "socio-cultural embeddedness" are significant, which the Wilks's Lambda values are 0.912 [F=4.48, p<0.01], 0.822 [F=10.03, p<0.01], 0.889

[$F=5.23$, $p<0.01$] and 0.898 [$F=5.226$, $p<0.01$] respectively. Meanwhile, over 9 out of 16 statements presented in these 4 constructs of the NOS are shown significant in the effect of academic background. The overall results of MANOVA test on academic background show participants with tertiary education background were more strongly constructivist in terms of their epistemological view on the NOS than participants with senior secondary background.

The results also indicate the differences between senior secondary and tertiary education (of science-related courses) would lead to the differentiation of students' epistemological view towards the NOS. And it is interpreted that the differences in learning experiences between two academic levels lead to the contrast view possessed by students. Comparing with tertiary education (such as university), the learning experience of students in high school is more dependent on textbook and teachers. MaComas (1998) argued in his research that the majority of high school science textbook communicate with absolute truth, and that scientists were using strict procedures to achieve certain scientific finding in the textbook. Meanwhile, Yalvac (2005) also concluded the science education in high school was representing idea through the authority of knowledge, while students were actually accepting the ideas due to the authority of teacher and textbook, instead of the evaluation of evidence.

Referring to the case in Hong Kong, even though the assessment authority takes practical work and science investigation into account, and introduced the development of students' scientific inquiry skills as one of the learning objective in the curriculum (HKEAA, 2015), more emphasis were put on the scientific knowledge in related science subjects. Consequently, Hong Kong secondary science education was still focusing on the low-level cookbook experience in terms of the experience of laboratory activity (Yip & Cheung; 2004; Tsang, 2004; Lau *et al.*, 2015).

The philosophy of constructivism highlights the active participation of learners in various learning activities, allowing learners to build up meaning from their experiences and connect with their prior knowledge (Driver, Asoko, Leach, Mortimer & Scott, 1994). Yet, the common approaches observed in secondary school basis neglected the process of students' thinking and cognitive construction, therefore cultivated a more universalist view on the NOS possessed by students which were reflected in this research. Students may therefore treat the knowledge and ideas illustrated in textbook or presented by teachers as the derivatives of objective and absolute observation, and any scientific inquiries required "standardized lab manuals" to perform step-by-step experiments.

4.4 Other highlight on the correlation of statements

Further correlation tests were performed regarding the statements in construct of "tentativeness". TEN2 (Q21), TEN3 (Q22) and TEN4 (Q23) were inputted to check for the Pearson correlation coefficient and the p value. Table 6 demonstrated the analysis results, showing a significant correlation between the responses of these three items. These three statements were designed as the constructivist statements related to tentativeness, with three different reasons explaining the tentative nature of science. For example, TEN2 stated:

> *Theories will be changed by time // because theories have been proven wrong by the development of technology and growth of knowledge.*

The former part of the statements required participants to determine whether it is a constructivist or universalist statements, while the latter part required participants to choose for the suitable reason. The proposed reasons in TEN2, TEN3 and TEN4 can be summarised as "falsification of prior knowledge" , "cumulative nature of scientific knowledge" and "reinterpretation of evidence" respectively.

Table 6. *Pearson Correlation Coefficient between responses of statement in "tentativeness" construct*

Items	TEN2 (Q21)	TEN3 (Q22)	TEN4 (Q23)
TEN2 (Q21)	1	r = 0.659 p <0.01	r = 0.505 p<0.01
TEN3 (Q22)		1	r = 0.544 p<0.01
TEN4 (Q23)			1

The result of high interdependency between the responses of these three statements arouse question whether students were able to identify the nature of tentativeness or were they responding the statements only by identifying the constructivist view of the statements. Liang *et al.* (2008) performed a similar investigation on students understanding of NOS, with an additional contextualized open-ended question at the end of each construct, asking participants to explain their answers. Most of the responses mentioned only whether or not theories would change or not, without mentioning the reasons or the nature behind the change. Therefore, it is hypothesized that participants were responding through memorizing statements of "tentativeness" instead of interpreting tentativeness by evidence. Further investigation have to be performed to check for this hypothesis.

Section 5: Conclusion, Implication and Limitation

The main interest of this research study was to investigate the epistemological view of students in Hong Kong on the NOS, and to compare the view possessed by different groups of students. As the descriptive data suggested, students in Hong Kong generally possessed a mixed and independent epistemological view towards different concepts of the NOS, and no interdependency could be observed in students responses. The further analysis of data suggested a significant subject (whether students studied Biology or not in HKDSE) and academic background (whether students were having senior secondary or tertiary education background) effect. Students who have studied Biology in HKDSE, or having tertiary education background were more likely to possess a constructivist view on the NOS. Meanwhile, the results also implies the restraints of senior secondary (high school) science education, where the high authority of teacher and textbook cultivates students to hold a more universalist view on the NOS.

Different instructional approach or pedagogies shall be applied in teaching and learning or performing laboratory activities in order to improve the comprehensiveness of students' understanding of the NOS. Kim & Irving (2010) suggested the application of historical science content in helping students to get a better understanding in the NOS. Historical events such as the modelling of DNA, discovery of atom and its structure recorded the progressive development of scientific knowledge. The nature of science would be expressed in the story of science history itself. Solomon et al. (1992) investigated the teaching of NOS with historical approach, and discovered students were having changes on the view of NOS such as "seeing theory as an explanation than facts", "understanding the purpose of experiment is as adding (or rejecting) validity of the hypothesis" and "understanding the influence of social events". It proves the use of historical approach in teaching the NOS brings more benefits to students, including a better learning of the concept of science, being more aware to the philosophy of science, constructing a better understanding of the social relevance of science and building up a better attitude of the public towards science.

Another approach that is suitable to be applied in teaching and learning activities is contextualized education (Clough, 2011; Hanuscin *et al.*, 2006). The contextualised contents of science, such as the inclusion of socio-scientific issues allow students to better understand the reasons of performing scientific inquiry, reasons of different research methods, dynamic nature of science and the influence of culture and society. The outbreak of COVID-19 in these years would be a favourable example for contextualised education in the topic of genetics, microbiology and infectious diseases. Students would be able to investigate how social events affect the objectives and research methods of the scientists, how scientists formulate hypothesis on the infection route of COVID-19 based on empirical evidences, and the dynamic nature of SARS-CoV-2 infection mechanism. The understanding of NOS of students was evaluated and shows significant improvement in findings from various researches (Burgin, 2015; Celik, 2020; Petersen et al., 2020), proven that contextualized education is seemingly a powerful tool to help laying a concrete foundation for students to comprehensively understand the NOS.

The finding and analysis of this research are made cautiously in light of the limitation of relatively small sample size. The samples were not randomly collected but using connivence sampling. Moreover, only 4 secondary schools and around 100 students from tertiary education are invited to participate in the research, which was a relatively small number comparing to the total number of students in Hong Kong, inhibiting the external generalization of this research findings. However, by including a diverse range in ages among both secondary and tertiary education, this research offers some insights into the general epistemological view on NOS possessed by Hong Kong students, which are able to serve as a foundation for teachers and educators to design and arrange for a more comprehensive science lessons, as well as teaching and learning activities.

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Appendix

Appendix 1:"Consensus view" of NOS content (adopted from Chang, Chang & Tseng, 2010)

The Tentative Nature of Scientific Knowledge: Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change
Observation, Inference, and Theoretical Entities in Science: Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses). By contrast, inferences are statements about phenomena that are not directly accessible to the senses.
The Theory-Laden Nature of Scientific Knowledge: Scientific knowledge is theory- laden. Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work.
The Creative and Imaginative Nature of Scientific Knowledge: Science is empirical. Nonetheless, generating scientific knowledge also involves human imagination and creativity.
The Social and Cultural Embeddedness of Scientific Knowledge: Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture
Scientific theories and laws: Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. Laws are descriptive statements of relationships among observable phenomena. Theories and laws are different kinds of knowledge, and one does not become the other
Myth of The Scientific Method: The myth of the scientific method is regularly manifested in the belief that there is a recipelike stepwise procedure that all scientists follow when they do science.

Appendix 2:“ FRA categories (Erduran & Dagher, 2014, as cited from Cheung, 2020)

Aims and values	The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices. These aims and values are often implicit, and they may include accuracy, objectivity, consistency, skepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power.
Scientific practices	The scientific enterprise encompasses a wide range of cognitive, epistemic, and discursive practices. Scientific practices such as observation, classification, and experimentation utilize a variety of methods to gather observational, historical, or experimental data. Cognitive practices, such as explaining, modeling, and predicting, are closely linked to discursive practices involving argumentation and reasoning.
Methods and methodological rules	Scientists engage in disciplined inquiry by utilizing a variety of observational, investigative, and analytical methods to generate reliable evidence and construct theories, laws, and models in a given science discipline, which are guided by methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to clearer understandings and more coherent explanations of scientific phenomena.
Scientific knowledge	Theories, laws, and models (TLM) are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations to develop scientific understanding. Scientific knowledge is holistic and relational, and TLM are conceptualized as a coherent network, not as discrete and disconnected fragments of knowledge.
Professional activities	Scientists engage in several professional activities to enable them to communicate their research, including conference attendance and presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding.
Scientific ethos	Scientists are expected to abide by a set of norms both within their own work and during their interactions with colleagues and scientists from other institutions. These norms may include organized skepticism, universalism, communalism and disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment.
Social certification	By presenting their work at conferences and writing manuscripts for peer-reviewed journals, scientists’ work is reviewed and critically evaluated by their peers. This form of social quality control aids in the validation of new scientific knowledge by the broader scientific community
Social values of science	The scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, and equality of intellectual authority.
Social organizations and interactions	Science is socially organized in various institutions including universities and research centers. The nature of social interactions among members of a research team working on different projects is governed by an organizational hierarchy. In a wider organizational context, the institute of science has been linked to industry and the defense force.
Political power structures	The scientific enterprise operates within a political environment that imposes its own values and interests. Science is not universal, and the outcomes of science are not always beneficial for individuals, groups, communities, or cultures.
Financial systems	The scientific enterprise is mediated by economic factors. Scientists require funding in order to carry out their work, and state- and national-level governing bodies provide significant levels of funding to universities and research centers. As such, these organizations have an influence on the types of scientific research funded, and ultimately conducted.

Appendix 3:" Questionnaire design of the epistemological view on NOS (modified from Kang, et al., 2004; Chen, 2006; Liang, et al., 2008; Park, et al., 2013)

Instruction:
The following statements describe different views regarding aspects of Nature of Science (NOS). Read the statement carefully and circle your opinion on the 1 to 5 scale on the right-hand side according to your scientific knowledge learnt in different science courses. There are no right or wrong answers for the questions in the questionnaire.
(1: Strongly disagree; 2: Disagree; 3: Neutral; 4: Agree; 5: Strongly agree)

Statements related to the Nature of science	Scale
Section 1	
1. Scientists' interpretation of the same observation [(1)] may be **different** because the scientists' prior knowledge [(2)] may affect their interpretation.	**SD D N A SA**
2. Scientists' interpretation of the same observation will be **the same** because the observed evidence are facts [(3)].	**SD D N A SA**
3. Scientists' interpretation of the same will be **the same** because scientists are objective [(4)].	**SD D N A SA**
Section 2	
4. Theories [(5)] and laws [(6)] are **discovered** by scientists because *they present in our daily life*.	**SD D N A SA**
5. Theories and laws are **discovered** by scientists because *they are based on experimental evidences*.	**SD D N A SA**
6. Theories and laws are **invented** by scientists because *they can be disproven* by other scientists.	**SD D N A SA**
7. Theories and Laws are **invented** by scientists because scientists invent laws *to interpret experimental evidences*.	**SD D N A SA**
Section 3	
8. Scientists **DO NOT** use their imagination and creativity because it is *not consistent with the logical principle of science*.	**SD D N A SA**
9. Scientists **DO NOT** use their imagination and creativity because it is *not objective*.	**SD D N A SA**
10. Scientists **DO** use their imagination and creativity *to explain why the result was observed*.	**SD D N A SA**
11. Scientists **DO** use their imagination and creativity *to collect data*.	**SD D N A SA**
Section 4	
12. Scientists follow the same step-by-step scientific method (i.e., observation, hypothesis, experiments, prove/disprove hypothesis) for research because ***it ensures true and accurate results***.	**SD D N A SA**
13. Scientists **use any different types of methods** to conduct their research for different inquiries.	**SD D N A SA**
14. Experiment is a **step-by-step procedure** to prove a proposed theory.	**SD D N A SA**

15. Experiment CANNOT prove any theories and hypothesis. It just **adds or reject the validity of the theories and hypothesis**.	**SD D N A SA**
Section 5	
16. Scientific research is NOT influenced by society and culture because *scientists are trained to conduct unbiased studies*.	**SD D N A SA**
17. Scientific research is NOT influenced by society and culture because it is *universal* and it applies everywhere.	**SD D N A SA**
18. Scientific research is influenced by society and culture as it determines *HOW scientists conduct their research*.	**SD D N A SA**
19. Scientific research is influenced by society and culture as cultural and social values determine *WHAT results scientists will accept*.	**SD D N A SA**
Section 6	
20. Theories **will not be changed** by time because it is based on unchanging evidence and facts.	**SD D N A SA**
21. Theories **will be changed** by time because theories have been proven wrong by the development of technology and growth of knowledge.	**SD D N A SA**
22. Theories **will be changed** by time because new discoveries and knowledge has been added on the prior theories.	**SD D N A SA**
23. Theories **will be changed** by time because scientists have new interpretation and explanation on the evidence.	**SD D N A SA**

Part II: Personal information

For the following questions, please tick for the appropriate choices in the boxes provided.

1. What is your age?

☐Below 16 ☐16 ☐17 ☐18 ☐19 ☐20 ☐21 ☐22 ☐23 ☐24 ☐24 or above

2. Are you studying senior secondary or tertiary education?

☐senior secondary education

☐tertiary education (bachelor / associate degree / higher diploma)

3. Which science subject(s) do/did you take in senior secondary education? (Tick all appropriate choices, please tick both subjects (e.g., Biology and Chemistry) if you take combined science)

☐Physics

☐Chemistry

☐Biology

- Thank you for completing the survey! –

List of definition/定義列表

1. Observation/觀察
   Observation is the act of noticing through human's five sense, such as seeing / hearing / smelling of an object / event directly. For example: I hear a thunder.
   觀察指運用人類的五觀（如用眼看，用耳聽），去獲取物件或事件發生的內容和信息。例如：「我聽見有雷電。」

2. Prior knowledge / 已有知識
   Prior knowledge is the information or educational content that a learner has already learnt before they receive/learn new information.
   已有知識是指學習者在吸收或學習新知識之前已經學習到的資訊/內容。

3. (Scientific) Facts /（科學）事實
   (Scientific) facts are the observations that have repeatedly confirmed and generally be accepted to be "true".
   （科學）事實指被重複進行的實驗所印證，與被廣泛人士接受為「真實」的觀察。

4. (Scientific) Objectivity /（科學）客觀
   (Scientific) objectivity is a concept that illustrate the way of research shall not be influenced by any perspectives, judgements, community bias, or personal interest.
   （科學）客觀指一種在進行科學研究時，不會被任何觀點、價值觀、社會經驗、個人利益等情況所影響的概念。

5. (Scientific) Theories /（科學）理論
   (Scientific) theories are the explanation of different phenomenon happened in the natural world by the use of scientific methods.
   For example: the "theory of evolution" suggested by Darwin explain the evolution process of species through "genetic variations" within species and "natural selection".
   （科學）理論是一種按照科學方法，對自然界的不同事物或現象的**解釋**。 例如「達爾文進化論」則通過「遺傳變異」與「自然選擇」解釋了生物演化的過程。

6. (Scientific) Laws （科學）定律
   (Scientific) laws are the description of phenomena happened in the natural world using scientific methods.
   For example: "Newton's second law" describe the quantitative relationship between force, acceleration, and the mass of an object.
   （科學）定律是指按照科學的方法，對自然界發生的現象進行**描述**。例如「牛頓的第二運動定律」則描述了自然界當中「力」、「速度」、與「質量」三者之間的關係。