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Teaching Science to Non-Science Students with Science Classics

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Abstract In Dialogue with Nature is a compulsory course on reading science-related classic texts for all students in the Chinese University of Hong Kong. The course aims to provide an opportunity for students to be familiar with the nature of science and develop their critical thinking skills. As the students are from diversified academic background, this situation has provided both positive and negative effects on the pedagogical strategies in this general education foundation course. For instance, while the course has provided a cross-disciplinary environment to stimulate the students to think beyond their own academic specialty, it has been speculated that students without prior scientific knowledge in high school could be disadvantaged in their academic performance. The intention of this paper is to report the current situation of this course and investigate the effectiveness of providing supplementary materials specifically to the non-science students. The preliminary analysis shows positive indicators on the effect.

Keywords: *science education, general education, classic texts, assessments, learning outcome*

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1. Introduction

1.1. In Dialogue with Nature

The Chinese University of Hong Kong (CUHK) introduced the General Education Foundation (GEF) programme specially designed for the four-year curriculum in 2010. Beginning from 2012, it becomes compulsory for all approximately 4000 students intake per year. GEF consists of two 3-unit courses, namely, In Dialogue with Humanity and In Dialogue with Nature. Through reading classic texts, students can discuss the core questions brought up by the classics and how these are put in modern context.

In particular, the list of readings for the course In Dialogue with Nature contains excerpts from science-related texts (see Table 1). These excerpts are compiled into the textbook of this course [1]. The list of readings comprises texts which are related to ancient Greek philosophies, ancient Chinese science and modern science. The texts are divided into three parts to address three main enquiries of human on Nature: Part I is about the human exploration of the physical universe; Part II is about the human exploration of the world of life; and Part III is about our understanding of human understanding itself.

According to Gjertsen's definition of science classics, they are "ones which transform science, or, in more fashionable language, which produce a major intellectual revolution" [2]. There are various advantages of using classic texts in science education. Firstly, the instrumental value of science may not be enough to sustain the students' interest in it, especially the non-science students. But reading science classics can let the students to learn about the great thoughts under historical, philosophical, social and cultural contexts, which differs from the traditional science textbook. Under this perspective, students would find science being profoundly relevant to them [3,4]. Secondly, as Muench has pointed out, "The value and appeal of using primary literature in the classroom are rooted in literature's unique potential to instruct students on the nature of scientific reasoning and communication" [5]. Such principle of scientific reasoning could touch upon many aspects in students' daily life [6]. Thirdly, as said by Wong Wing Hung, the deputy director of the GEF programme, in the introduction for the textbook of the course [1]:

"This course invites students to retract the train of thought of our predecessors in this quest for knowledge, and with whose writings students will engage in dialogues. By following the footsteps of great minds, students shall develop informed views about nature and human interactions with it."

As the aim of this course is more related to the reflection on the revolutionary thoughts towards nature from the great thinkers under historical and cultural contexts, instead of teaching any particular scientific knowledge, it was anticipated that it is suitable for all undergraduate students to take this course regardless of their previous science education. Through reading the original texts, this course also provides an opportunity for students to develop their critical thinking skills and to assess their own meaning of life and other value-related issues.

Table 1. Lists of readings for In Dialogue with Nature since 2012

Part I: Human Exploration of the Physical Universe
• Republic / *Plato*
• The Beginnings of Western Science / *David C. Lindberg*
• The Birth of a New Physics / *I. Bernard Cohen*
• The Principia: Mathematical Principles of Natural Philosophy / *Isaac Newton*
Part II: Human Exploration of the World of Life
• On The Origin of Species / *Charles Darwin*
• DNA: The Secret of Life / *James D. Watson*
• Silent Spring / *Rachel Carson*
Part III: Our Understanding of Human Understanding
• Science and Method / *Henri Poincaré*
• In Search of Memory: The Emergence of a New Science of Mind / *Eric R. Kandel*
• The Shorter Science and Civilisation in China / *Joseph Needham*
• Why the Scientific Revolution Did Not Take Place in China — or Didn't It? / *Nathan Sivin*
• Brush Talks from Dream Brook / *Shen Kua*
• The Mathematical Universe / *William Dunham*
• Elements / *Euclid*

There are five official intended learning outcomes (ILOs) of the course [7]:

1. read and discuss science texts with confidence.
2. identify the essential characteristics of various methods of scientific inquiry that have significant impacts on how human beings view life and universe.
3. formulate informed personal views on the societal implications of scientific explorations.
4. relate the development in natural sciences highlighted in the course to contemporary human conditions.
5. evaluate the scopes of application, achievement and limitations of highlighted scientific methods using multiple perspectives.

In order to promote student-oriented learning, discussion-based tutorial is deemed a key component of this course. The weekly structure of the course consists of a two-hour student-oriented tutorial and a one-hour lecture. Each tutorial class would usually consist of a maximum of 25 students with well-mixed academic backgrounds. This is deemed a constructive atmosphere for students to exchange ideas across disciplines.

2. Evaluation of the Course

The effectiveness of the course In Dialogue with Nature and GEF programme as a whole has been assessed by an external reviewer, Jerry Gaff, Senior Scholar of Association of American Colleges and Universities, in 2014. In his formative evaluation report [8], it is noted that "there is considerable evidence from students and teachers alike that students are achieving important learning outcomes; enhanced reading ability and critical analysis, confidence in confronting difficult texts, open-mindedness and appreciation for intellectual diversity, and self-discovery of their own interests, abilities, and tastes." Association for General and Liberal Studies (AGLS) also recognized the GEF programme with an award for Exemplary International General Education Program Improvement in 2015. The awards assessment criteria can be found in [9].

To further understand the effectiveness of the course as measured from students' perception, two student surveys, namely entry and exit surveys, were conducted at term start and term end in Fall term 2014-15. This survey design allows us to measure the status of students at two different time points. The data gathered in the entry survey can act as a defined baseline to evaluate the changes of students after taking the course. In this case, the effectiveness of the course was judged in terms of how much improvement takes place [10]. The surveys were designed to look into students' backgrounds, their effort spent on the course, their self-perceived achievements in the ILOs and their views toward the effectiveness of various learning methods.

The surveys were distributed anonymously for both the entry and exit surveys. No personally identifiable information was asked so as to protect students' identity. The entry survey, conducted at term start, was pre-assigned with a three-digit tag number. As the survey sheets were randomly distributed to the students, the tag number on each questionnaire was only known by that student. The exit survey, conducted at term end, required each student to fill in the tag number from his/her entry survey. This procedure allowed tracking of each individual students yet preserving anonymity.

A total of 435 students enrolled in the surveyed classes. 408 students participated in the entry survey and 381 students participated in the exit survey. These differences are mainly caused by the student's late add-drop to the course and absence to classes. Among them, 228 students were tagged successfully under the mentioned procedure. The remaining students were excluded as they are unable to retrieve the tag number at the end of the course. The following analysis will be based on the results from the tagged students.

2.1. Evaluation Result

Twelve questions that appear identically on both the entry and exit surveys were directly related to the course ILOs. Students were asked to self-assess their perceived attainment of the ILOs in a 6-point Likert scale, from strongly disagree to strongly agree, at the beginning and at the end of the course.

The average scores are presented in Table 2. Comparing the scores between the entry and exit surveys, students have a significant increase of perceived attainment in all ILOs ($p<.01$ in paired two-tailed Student's t-test). These increments (Δ) are indicated by the positive values when the entry scores are subtracted from the exit scores in the last column. Encouragingly, these increments range from +0.23 to +1.40, with an average of +0.68, suggesting that the course has met its intended goals.

The twelve ILO-related questions can be classified according to Bloom's taxonomy [11,12]. Questions 1 and 3 are within the affective domain while the remaining questions are within the cognitive domain. The cognitive domain questions are subdivided into course-specific (Q2, 10, 11 and 12) and generic skills (Q4 to 9). We observed that the changes of students' perception in the course-specific questions within the cognitive domain (Q2, 10, 11 and 12) were more dramatic. The score differences range from +0.93 to +1.40, with an average of +1.08. Meanwhile, the changes of students' perception in questions related to the affective domain and the generic skills within the cognitive domain (Q1, 3 to 9) were to a lesser degree, with score differences range from +0.23 to +0.69, averaging +0.49. This suggests that students generally focus more on disciplinary knowledge than on generic skills, which coheres with a previous study [13].

The survey data were also analyzed by treating it as dichotomous categorical data as in [10]. Table 3 reported the percentage of students who rated 5 or 6 in the 6-point Likert scale in the ILO-related questions in the entry and exit surveys. On average, 61.2% of the students rated 5 or 6 to the ILO-related questions in the exit survey, up from 29.5% in the entry survey. Similar to the previous analysis in Table 2 on the change of students' perception, students have a significant increase of perceived attainment in all ILOs (p<.05 in McNemar's test). In essence, the course has been effective in converting a good percentage of students from tending towards disagreeing to agreeing with the ILOs-related questions.

Table 2. ILO-related questions in the Entry and Exit Surveys (in a 6-point Likert scale)

ILO-related questions	Entry	Exit	∆*
Q1. I am interested in natural science.	4.24	4.78	+0.54
Q2. I understand the development of natural science.	3.08	4.48	+1.40
Q3. Scientific knowledge is important for my intellectual development.	4.43	4.91	+0.48
Q4. I can analyze and evaluate arguments critically.	4.07	4.76	+0.69
Q5. I am open to new and different ideas.	4.81	5.04	+0.23
Q6. I am confident in reading science-related texts.	3.97	4.43	+0.46
Q7. I am confident in reading difficult texts in English.	3.66	4.18	+0.52
Q8. I can articulate clearly my ideas in writing.	4.04	4.52	+0.48
Q9. I can express clearly my ideas orally.	3.94	4.45	+0.51
Q10. I understand various features of scientific methods.	3.77	4.70	+0.93
Q11. I understand the contributions and limitations of scientific inquiry.	3.85	4.87	+1.02
Q12. I can assess the social implications of scientific inquiry.	3.80	4.75	+0.95

Notes: * (1) ∆ indicates Exit scores minus Entry scores.
(2) Differences are all statistically significant at $p \leq .01$.

Course-specific questions in the cognitive domain (Q2, 10, 11 and 12) showed the greatest percentage increase (ranging from +44.3% to +47.5%) when subtracting the percentage in entry survey from exit survey. Questions regarding the generic skills and affective outcomes had a lesser percentage increase (ranging from +9.2% to 37.7%).

Table 3. ILO-related questions in the Entry and Exit Surveys (percentage of students who rated 5 or 6 in a 6-point Likert scale)

ILO-related questions	Entry (%)	Exit (%)	∆ (%)*
Q1. I am interested in natural science.	43.8	68.9	+25.1
Q2. I understand the development of natural science.	7.0	53.5	+46.5
Q3. Scientific knowledge is important for my intellectual development.	46.0	72.9	+26.9
Q4. I can analyze and evaluate arguments critically.	28.5	66.2	+37.7
Q5. I am open to new and different ideas.	73.7	82.9	+9.2
Q6. I am confident in reading science-related texts.	29.0	50.0	+21.0
Q7. I am confident in reading difficult texts in English.	24.1	38.5	+14.4
Q8. I can articulate clearly my ideas in writing.	27.2	51.7	+24.5
Q9. I can express clearly my ideas orally.	25.4	47.4	+22.0
Q10. I understand various features of scientific methods.	20.2	64.5	+44.3
Q11. I understand the contributions and limitations of scientific inquiry.	24.6	71.1	+46.5
Q12. I can assess the social implications of scientific inquiry.	18.8	66.3	+47.5

Notes: * (1) ∆ indicates Exit scores minus Entry scores.
(2) Differences are all statistically significant at $p \leq .05$.

Table 4. ILO-related questions in the Entry and Exit Surveys grouped by high school science background (percentage of students who rated 5 or 6 in a 6-point Likert scale)

Questions	With science background			Without science background		
	Entry (%)	Exit (%)	∆ (%)*	Entry (%)	Exit (%)	∆ (%)*
Q1. I am interested in natural science.	50.0	74.2	+24.2	16.7	45.2	+28.5
Q2. I understand the development of natural science.	8.0	56.4	+48.4	2.4	40.5	+38.1
Q3. Scientific knowledge is important for my intellectual development.	47.3	74.2	+26.9	40.5	66.7	+26.2
Q4. I can analyze and evaluate arguments critically.	28.0	65.6	+37.6	31.0	69.0	+38.0
Q5. I am open to new and different ideas.	73.2	82.2	+9.0	76.2	85.7	+9.5
Q6. I am confident in reading science-related texts.	31.7	53.3	+21.6	16.7	35.7	+19.0
Q7. I am confident in reading difficult texts in English.	25.8	40.3	+14.5	16.7	30.9	+14.2
Q8. I can articulate clearly my ideas in writing.	26.9	50.5	+23.6	28.6	57.1	+28.5
Q9. I can express clearly my ideas orally.	27.5	49.5	+22.0	16.7	38.1	+21.4
Q10. I understand various features of scientific methods.	24.2	66.6	+42.4	2.4	54.8	+52.4
Q11. I understand the contributions and limitations of scientific inquiry.	26.9	72.6	+45.7	14.3	64.3	+50.0
Q12. I can assess the social implications of scientific inquiry.	20.4	67.7	+47.3	11.9	59.5	+47.6

Notes: * (1) ∆ indicates Exit scores minus Entry scores.

The next step is to analyze if there are any differences in students' perception on ILOs attainment with respect to their high school science background (Table 4). 42 out of 228 students who were successfully tagged in the survey did not have any high school science background, a piece of information collected by the entry survey. In terms of the overall change of the perception of ILOs attainment, there were on average 30.3% more students with high school science background who rated 5 or 6 towards the twelve questions after taking the course. A similar response was observed for students without high school science background (31.1%). Therefore, the impact of the course to both groups of students has no notable difference.

However, if the focus is on the absolute outcome indicated by the exit survey alone (instead of relative to the entry scores), an average of 62.8% of students with high school science background rated 5 or 6 to the twelve questions, while only 54.0% of students without high school science background felt the same. In particular, for those without high school science background, their confidence in reading science-related texts (Q6, 35.7%), confidence in reading difficult English texts (Q7, 30.9%) are areas with especially lower scores.

3. Supplementary Materials for Non-science Students

Results from section 2 indicate that students on average have been positive about their attainments of the ILOs. It is of concern that, however, students without high school science background were seemingly underperforming. As aforementioned in section 1, this course is a compulsory course for all undergraduate students studying at the CUHK and hence provided classes of well-mixed students from various faculties. While this student diversity inside the tutorial class is itself a benefit for generating the necessary discussion atmosphere, it could also impose a serious challenge in designing pedagogical strategies as the level of previous science education is highly uneven.

It was deemed that the main aim of this course was to enhance student's understanding and appreciation of the nature of science and therefore the student's previous science education is unnecessary. However, teachers of the course often reported that their students might not all agree to this assertion. This view of the students is not totally ungrounded. For example, this course involves the understanding of some historical explanations of nature which sometimes involves mathematical equations and scientific terminologies. This can be a hindering factor for those students without science background to even get into the main point of arguments of the texts. These non-science students, while having the ability to comprehend the core questions brought up by the classics, were often being discouraged when they encounter unfamiliar scientific terminologies and concepts. Moreover, they could not easily make comparison between the historical explanations and the modern explanations simply because they are unaware of the latter. They could lose their patience and interests to dig further because they could not overcome this barrier to get into the core questions in the texts. Levelling the gap between science and non-science students by providing additional help in this aspect is therefore deemed as important, if not critical to the teaching of this course.

For this reason, an attempt has been made to supplement this particular group of students. A series of short supplementary lectures explaining basic scientific knowledge in a way that is tailor-made for In Dialogue with Nature have been conducted in parallel to the teaching of the course starting from the Fall term of 2014-15. While high school science classes usually focus on calculations and memorizing formulas and equations, this supplementary lecture series focused on introducing modern explanations of nature and how these are different from the historical explanations. By illustrating these explanations with lively examples, non-science students can quickly understand the competing explanations. They could then assess the pros and cons of these explanations through which they can practise their critical thinking skills. Ultimately, they could gain confidence and interest in further exploring more in the nature of science.

There were in total three sets of supplementary lectures conducted. Table 5 listed the topics covered in these three sets.

Table 5. List of topics covered in the supplementary lectures

Physics	Definitions in Physics, (Mass, Momentum, etc)
	Newton's 3 Laws
Biology	Definitions in Ecology and Biology (Food Web, Species, etc)
	Cell Biology (Chromosomes, DNA, etc)
	Modern Evolutionary Theory
Chemistry	Atomic theory and Periodic table
	Changes and Reactions
	Biochemistry

These supplementary lectures, which are non-credit bearing and optional, could unavoidably be brief in comparison to standard science courses. Hence, interested students would often have a desire to think through the concepts repeatedly in a longer period. For this reason, an online platform for this purpose is developed [14]. This platform provides the recorded lectures online for students to watch at their own time and at their own pace. The platform also includes a series of online exercises to serve as checkpoints for the students who are watching the recorded lecture.

4. Evaluation of the Supplementary Materials

This section is to report the investigation on the effectiveness of the supplementary materials. It should be noted that, while the results of this investigation have specific importance to the teaching of the course In Dialogue with Nature, the analysis could also have general relevance to the use of classic texts in science education.

4.1. Evaluation by Survey

To investigate the effect of the supplementary materials, the 228 tagged students were split into two groups. An experimental group of 55 students were provided with the access of the supplementary materials in Fall 2014-15. The remaining 173 students had no access to the supplementary materials during the same term served as the control group for comparison.

Table 6 listed the comparison between the two groups of students. The two columns labelled "With" supplementary materials and "Without" supplementary materials" each indicates the difference of percentage of students who rated 5 and 6 to the list of ILO-related questions between the entry and exit surveys. The column labelled "Δ" indicates the difference between the first two columns.

The difference in here represents how much more students by percentage has been converted with the supplementary materials. As can be seen in Table 6, the percentages ranged from -7.3% to 24.6% with an average of 9.6%. This shows that the supplementary materials have generally provided a positive effect.

Table 6. Change of students' perception towards ILO-related questions "With" and "Without" supplementary materials (percentage of students who rated 5 or 6 in a 6-point Likert scale)

ILO-related questions	Exit minus Entry		Δ (%)*
	With (%)	With-out (%)	
Q1. I am interested in natural science.	+ 30.9	+ 23.2	+7.7
Q2. I understand the development of natural science.	+ 52.8	+ 44.5	+8.3
Q3. Scientific knowledge is important for my intellectual development.	+ 45.4	+ 20.8	+24.6
Q4. I can analyze and evaluate arguments critically.	+ 34.5	+ 38.8	-4.3
Q5. I am open to new and different ideas.	+ 3.7	+ 11.0	-7.3
Q6. I am confident in reading science-related texts.	+ 31.0	+ 17.9	+13.1
Q7. I am confident in reading difficult texts in English.	+ 23.7	+ 11.6	+12.1
Q8. I can articulate clearly my ideas in writing.	+ 38.1	+ 20.3	+17.8
Q9. I can express clearly my ideas orally.	+ 36.3	+ 17.4	+18.9
Q10. I understand various features of scientific methods.	+ 56.3	+ 40.4	+15.9
Q11. I understand the contributions and limitations of scientific inquiry.	+ 47.3	+ 46.2	+1.1
Q12. I can assess the social implications of scientific inquiry.	+ 52.7	+ 45.7	+7.0

Notes: * Δ indicates percentage "With" supplementary material minus "Without" supplementary material.

The next question to investigate is whether the supplementary materials are particularly helpful to students with no prior high school science background (the 'non-science students'). Among the students provided with the access of the supplementary materials in Fall 2014-15, 15 of them were non-science students. There were 27 non-science students who were not given the supplementary materials. The results are shown in Table 7.

With this selected comparison, the differences ranged from -8.7% to 35.9% with an average of 13.5%. This average is higher than the average generated from the data reported in Table 6 suggesting that the supplementary lecture is more effective to the non-science students as intended.

In particular, the effects on questions 2, 3, 6, 7, 8 and 10 are noticeability higher than the other questions. This seems to indicate that the supplementary materials have brought a positive effect on the understanding of science and the confidence of reading in this course, whereas it has brought no noticeably additional effect on students' perception as reflected by the result for questions 1, 4, 5, 11 and 12. This dichotomy of results matched the purpose of the supplementary materials.

Table 7. Change of non-science students' perception towards ILO-related questions "With" and "Without" supplementary materials (percentage of students who rated 5 or 6 in a 6-point Likert scale)

ILO-related questions	Exit minus Entry		Δ (%)*
	With (%)	With-out (%)	
Q1. I am interested in natural science.	+19.9	+28.6	-8.7
Q2. I understand the development of natural science.	+53.3	+28.6	+24.7
Q3. Scientific knowledge is important for my intellectual development.	+46.6	+10.7	+35.9
Q4. I can analyze and evaluate arguments critically.	+40.0	+39.3	+0.7
Q5. I am open to new and different ideas.	+6.7	+14.2	-7.5
Q6. I am confident in reading science-related texts.	+33.2	+10.7	+22.5
Q7. I am confident in reading difficult texts in English.	+26.7	+7.2	+19.5
Q8. I can articulate clearly my ideas in writing.	+46.7	+17.8	+28.9
Q9. I can express clearly my ideas orally.	+26.7	+17.9	+8.8
Q10. I understand various features of scientific methods.	+73.3	+39.3	+34.0
Q11. I understand the contributions and limitations of scientific inquiry.	+53.4	+46.4	+7.0
Q12. I can assess the social implications of scientific inquiry.	+46.7	+50	-3.3

Notes: * Δ indicates percentage "With" supplementary material minus "Without" supplementary material.

4.2. Evaluation by Academic Performance

It is deemed that academic performance could also be an important indicator for assessment of the effectiveness of the supplementary materials. A comparison of the academic performance between students provided with and without supplementary materials is conducted. Since the surveys are anonymous, the reported science literacy cannot be used to trace their academic performance. Instead, students are divided by their belonging faculty. Students from the faculty of Science, Engineering, Medicine, Business and three Social Science programmes (Economics, Geography and Psychology) are considered the "science students" while students from the faculty of

Social Science (except Economics, Geography and Psychology), Arts, Law and Education are grouped as the "non-science students".

In order to maintain consistency of the marking schemes and grading standards for a valid comparison, the data set of the two groups are extracted only from students taught by a single lecturer. The experimental group belongs to the students from the Fall term of 2014-15 in which the lecturer has provided the supplementary materials; the control group belongs to the students from the Spring term of 2013-14 in which the group was taught by the same lecturer but without the supplementary materials.

Among the 129 students in Spring term 2013-14, there were 92 "science students" and 37 "non-science students". The 137 students in Fall term 2014-15 has a similar split: 94 "science students" and 43 "non-science students". The number of students who obtained A or A- in their final grade of this course from these two semesters are tabulated in Table 8 and Table 9.

In the Spring term of 2013-14, all the A grades are obtained by the "science students". In percentage, 34.8% of the "science students" can achieve an A or an A- grade in this course as compared to 18.9% for the "non-science students". This result might comply with the concern of the non-science students that lacking previous science education is disadvantaged in studying this course.

Table 8. Science vs Non-science students in academic performance in Spring term 2013-14

Without supplementary materials (spring term 2013-14)	**Science students**	**Non-Science students**
Number of students who received **A**	11	0
Number of students who received **A-**	21	7
Percentage of students who received **A** or **A-**	34.8%	18.9%

In comparison, in the Fall term of 2014-15 when the supplementary materials were provided, the A grades are no longer dominated by the "science students". 2 out of the 43 "non-science students" received an A grade when only 6 out of the 94 "science students" received an A grade. In percentage, 35.1% of the "science students" can receive an A or an A- grade, which is not significantly different from the 34.8% when the supplementary materials were not provided. However, the percentage for the "non-science students" increased to 23.3%, up from 18.9%. The percentage gap between the two groups of students shrank from 15.9% to 11.8%.

Table 9. Science vs Non-science students in academic performance in Fall term 2014-15

With supplementary materials (fall term 2014-15)	**Science students**	**Non-science students**
Number of students who received **A**	6	2
Number of students who received **A-**	27	8
Percentage of students who received **A** or **A-**	35.1%	23.3%

5. Conclusion

Analysis has been conducted to measure the effectiveness of the teaching of the course In Dialogue with Nature and its supplementary material for non-science students. On top of existing external program review, the effectiveness is mainly measured by student surveys supported by students' academic performance in this research. The preliminary analyzed results indicated that our course can significantly enhance student's interest and understanding on natural science. Meanwhile, there is a significant increment on confidence in reading science text and understanding of the importance of science upon the implementation of supplementary material. It is expected that better understanding of the effectiveness of supplementing students' background science knowledge could assist the teachers in delivering the classic-based science courses in the most suitable way in the future.

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