Exploring the dynamic interplay of college students' conceptions of the nature of science

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Abstract

This study attempts to determine whether there exists a negative interconnection between the creative and testable nature-of-science (NOS) conceptions in college students' conceptual ecology by investigating, through a pair of IHV-assisted teaching experiments, the effect of raising the status of each NOS conception in students' conceptual ecology on that of the other. 216 Taiwanese college non-science majors enrolled in two separate sections of an introductory general science course were randomly assigned to the two treatment groups of the study. During the 12-week experiments, students in each group were "treated" with a common core curriculum interspersed with a set of Interactive Historical Vignettes (IHVs) that highlight the particular aspect of NOS under investigation. Pretest and posttest measures of students' NOS views were collected by administering the Chinese version of the Nature of Scientific Knowledge Scale before and immediately after the experiments. The dependent t-test was used to evaluate the research hypotheses of both experiments. Results confirm that there is indeed a negative, seesawing-at-a- distance type of interconnection between the creative and testable NOS conceptions in college students' conceptual ecology. The cause for such phenomena remains open to further investigation.

Introduction and Background

Helping all students develop a basic understanding about the nature of science (NOS) is a common goal of contemporary science education reform worldwide (DES/Welsh Office, 1995; Ministry of Education, 2001; National Research Council, 1996; Rutherford & Ahlgren, 1990). However, recent research consistently shows that most students do not possess an adequate understanding of the nature of science (Chin, 2002; Lederman, 1992; Meichtry, 1993; Solomon, 1994). To improve the situation, many researchers recommended using the history of science to help students develop more accurate views about the nature of science (Duschl, 1990; Hsu & Lee, 1995; Matthews, 1994; Monk & Osborne, 1997). However, since most science teachers today are already required to "cover" more material than time allows, they usually have no choice but to focus on teaching the required science content while leaving the development of student understanding of the nature of science to chance. The history and nature of science thus remains to be a "non-essential component" in most science courses today, serving merely as a footnote to the science curriculum (Lemke, 1990).

As an attempt to help science teachers revitalize the history and nature of science in their science classes under the practical constraints, Wandersee (1990) has recently developed an innovative educational tool – Interactive Historical Vignettes (IHVs) – that enables science teachers to add a historical and philosophical dimension to regular science instruction with little investment in time and no reduction in content coverage. The IHVs are carefully crafted, historically accurate short stories (10-15 minutes) that describe some brief episode from the life of a scientist which characterizes certain aspects of the NOS and provides a historical perspective on the science topic under study. Developed based on Egan's (1986) story form model, the IHVs employ the *interrupted story form and binary opposites* involving conflict to generate student participation and spark discussion about the NOS. Its "delivery system" consists of an elegant instructional technique that combines the story-telling method with the discussion method. As shown in *Figure 1*, the essence of this technique involves breaking the IHV story at the point of conflict, asking students to predict its resolution, revealing the historical resolution of the conflict, and helping students refine their NOS views in follow-up classroom discussions. In recent years, Wandersee and his research associates have successfully used the IHVs to teach the nature of science in elementary, secondary, as well as college science classes (Roach, 1993; Wandersee, 1992; Wandersee & Roach, 1998). These initial successes suggest that the IHVs might also be used by science teachers in Taiwan to safely "smuggle" some history and nature of science into their science classrooms under the practical constraints.

In order to find out whether the IHVs really can effectively enhance Taiwanese students' understanding about the nature of science, the author (Chan, 2003) recently conducted a pretest-posttest control-group design, quasi-experimental study to investigate the impact of infusing the IHVs into existing high school science courses in Taiwan on students' views of the amoral, creative, developmental, parsimonious, testable, and unified NOS summarized in Appendix I by Rubba and Andersen (1978). The results of the study not only provided conclusive evidence for the mind-altering effects of the IHVs on students' NOS views, but also uncovered by accident an intriguing phenomenon that demands further investigation. Namely, while the creative and testable NOS conceptions were considered consistent in Rubba and Andersen's (1978) model of the nature of scientific knowledge, they seemed to be so incompatible with each other in students' conceptual ecology that they appeared to engage in a seesawing battle against each other throughout the experiment.

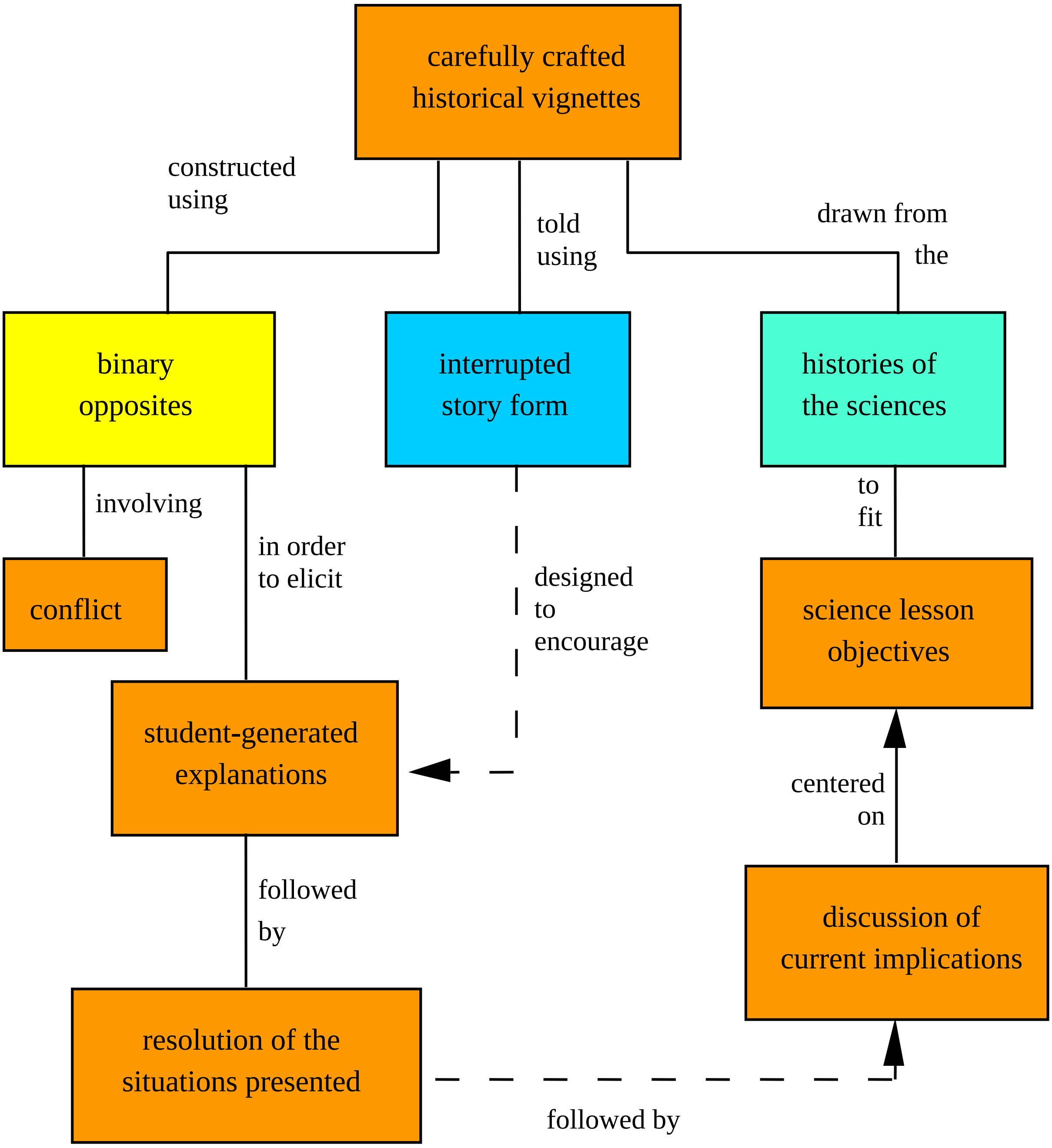
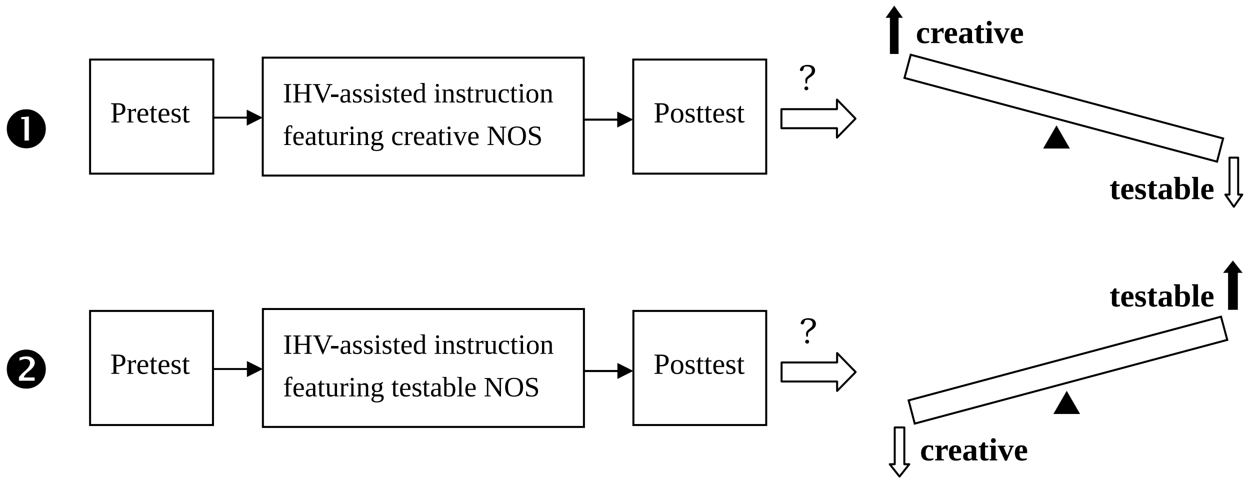


Figure 1. Concept Map of the Interactive Historical Vignettes (Wandersee, 1992)

As the first step toward solving the mystery about the above intriguing phenomenon, the current study employed a novel research design that uses the focus of the previous study – the IHVs – as a research tool to induce conceptual change in college students' conceptions of the NOS and tried to ascertain whether there exists a negative, seesawing-at-a-distance type of interconnection between the creative and testable

NOS conceptions in such students' conceptual ecology by conducting a pair of IHV-assisted "twin experiments" depicted below.



Purpose

The purpose of the present study was to determine whether there exists a negative interconnection between the creative and testable NOS conceptions in college students' conceptual ecology by investigating, through a pair of IHV-assisted experiments, the effect of raising the status of each NOS conception in students' conceptual ecology on that of the other.

Theoretical Base

The Conceptual Change Model of Learning (CCM) developed by Posner, et al. (1982), which recognizes the *interdependence* of students' views of the various aspects of NOS and conceives learning the NOS as a process of conceptual change involving the *dynamic interplay* of a complex network of interconnected NOS conceptions in students' conceptual ecology, provides the theoretical justification for this study.

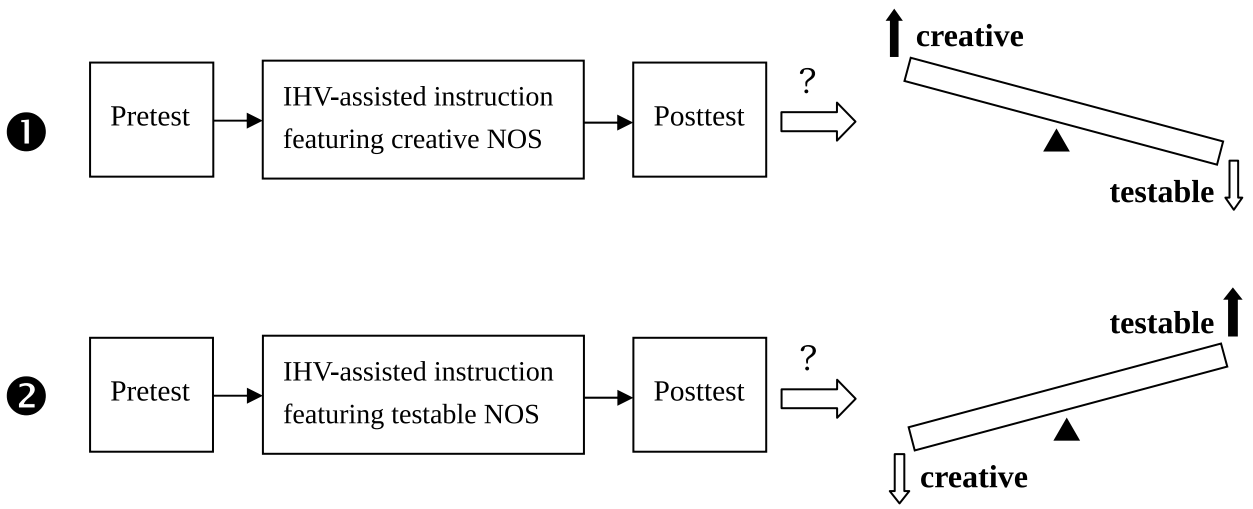
According to Posner, et al. (1982), CCM views learning as a process of conceptual change that occurs against the background of learners' current conceptions and asserts that a person will accept a new conception only if the following *conditions* are met within the context of his or her *conceptual ecology*. First, the new conception must be intelligible. Second, the new conception must appear initially plausible. Third, the new conception must seem potentially fruitful. The extent to which a conception meets these three conditions is termed the *status* of that conception (Hewson & Thorley, 1989) and the more conditions a conception meets, the higher is its status. Learning a particular NOS conception thus implies that its status rises. However, since students' conceptions of the various aspects of the NOS do not exist in isolation from one another but are interconnected with one another in their conceptual ecology, raising the status of a particular NOS conception inevitably results in concomitant status-shifts in other closely connected NOS conceptions. Furthermore, since students' NOS conceptions are embedded in a web of inter-connected NOS conceptions and often come with their own "cognitive support group" (Strike & Posner, 1992, p. 154) that helps them resist modification, the learning of NOS inevitably involves the dynamic interplay of a complex network of interconnected NOS conceptions in students' conceptual ecology and is best viewed as a dynamic mind-altering process in which the *relative status* of a particular NOS conception is raised above those of its competitors.

Because the way in which the various NOS conceptions are connected with one another in students' conceptual ecology determines how their relative status would change as each is being learned, one should in principle be able to infer the nature of their interconnections by investigating how the various NOS conceptions reposition themselves in students' conceptual ecology as the status of each conception is raised. As a direct application of this principle, this study tries to clarify the nature of the interconnection between the creative and testable NOS conceptions in college students' conceptual ecology by investigating, through a pair of IHV-assisted experiments, the effect of raising the status of the creative NOS conception in students' conceptual ecology on that of the testable NOS conception, and vice versa.

Research Design and Methodology

In order to ascertain whether there is indeed a negative, seesawing-at-a-distance type of relationship between the creative and testable nature-of-science conceptions in college students' conceptual ecology, a pair of IHV-assisted "twin experiments" depicted below were conducted to investigate the following pair of research questions:

1. Does raising the status of the creative NOS conception in college students' conceptual ecology cause the status of the testable NOS conception to drop lower simultaneously?
2. Does raising the status of the testable NOS conception in college students' conceptual ecology cause the status of the creative NOS conception to drop lower simultaneously?



A total of 216 Taiwanese college non-science majors enrolled in two separate sections of an introductory general science course taught by the author participated this study. Each section was randomly assigned to one of the two treatment groups of the study: *the creative group and the testable group*. During the 12-week teaching experiments, students in each group were "treated" with a common core curriculum interspersed with a series of specially designed IHVs that highlight the particular aspect of the NOS under investigation. In Experiment 1, a 15-minute IHV featuring the creative NOS was injected into the creative section of the course once every two weeks for 12 weeks. In a similar manner, a testable IHV was infused into the testable section every other week during the 12-week treatment period in Experiment 2. *Appendix II* shows a typical creative IHV used in this study.

Student views of the creative and testable NOS were measured by the Chinese version of Nature of Scientific Knowledge Scale (CNSKS) translated and validated by the author for use with Taiwanese students in a previous study (Chan, 2003). The CNSKS is a 48-item Likert-type instrument with 6 subscales designed to measure secondary and college student' views of the amoral, creative, developmental, parsimonious, testable and unified NOS summarized in Rubba & Andersen (1978). Each subscale contains 8 items and can be used separately to measure the *status* of the corresponding NOS conception in students' conceptual ecology. *Table I* summarizes the reliability of each CNSKS subscale obtained in this study.

Subscale	**No. of Items**	**Range of Scores**	**CNSKS Alpha** (N=216)
Amoral	8	8-40 (Neutral:24)	0.76
Creative	8	8-40 (Neutral:24)	0.82
Developmental	8	8-40 (Neutral:24)	0.65
Parsimonious	8	8-40 (Neutral:24)	0.62
Testable	8	8-40 (Neutral:24)	0.70
Unified	8	8-40 (Neutral:24)	0.78

Table 1 Reliabilities of CNSKS Subscales

Pretest and posttest measures of students' NOS views were collected by administering the CNSKS before and immediately after the 12-week teaching experiments. *The dependent t-test* statistical procedure was used to analyze the data and evaluate the following pair of research hypotheses, using an alpha value of 0.05 for all statistical tests.

1. Raising the status of the creative NOS conception in college students' conceptual ecology causes the status of the testable NOS conception to drop lower simultaneously.
2. Raising the status of the testable NOS conception in college students' conceptual ecology causes the status of the creative NOS conception to drop lower simultaneously.

Findings and Conclusion

The results of statistical analysis summarized in *Table II* and *Table III* indicate that the 12-week creative-IHVs treatment in Experiment 1 has not only substantially increased students' originally limited understanding of the creative NOS (19.04 ->

23.18) but also resulted in a concomitant reduction in their strong belief in the testable NOS (31.90 -> 31.03) whereas the testable-IHVs treatment in Experiment 2 caused both a moderate increase in students' enthusiastic support for the testable NOS (29.31 ->31.60) and a concomitant decrease in their limited understanding of the creative NOS (21.59 -> 19.62). *Figure 2* and *Figure 3* further reveal that the status of the creative and testable NOS conceptions for both treatment groups consistently move *against* each other from pretest to posttest as if they were riding on the opposite ends of a seesaw.

Taken together, these findings demonstrate that the creative and testable NOS conceptions are so *negatively interconnected* with each other in college students' mind that one can not raise the status of either conception without simultaneously lowering that of the other. As a result, it was concluded that there is indeed a negative, seesawing-at-a-distance type of interconnection between the creative and testable NOS conceptions in these students' conceptual ecology.

In addition to providing conclusive evidence for the existence of a negative interconnection between the creative and testable NOS conceptions in college students' conceptual ecology, this study also helps us develop a better understanding of *how* the relative status of these two rivaling NOS conceptions might change in response to instruction that focuses specifically on either one of them. Such understanding in turn leads us to see that the problem with current college science curricula in Taiwan is that they focus so exclusively on the testable aspect of the NOS that they make it extremely difficult for students to see both the dominant testable NOS and its creative rival simultaneously. As a result, it provides strong theoretical justification for shifting some of the focus of current college general science courses to revealing the inherent tentative and creative nature of science by supplementing them with a series of specially designed IHV stories that illuminate both the creative and the testable aspects of the nature of science.

CNSKS subscale	**Experiment 1 (N=94)**		**Experiment 2(N=122)**	
	pretest	posttest	pretest	posttest
Amoral	26.72	27.00	26.57	27.22
Creative	19.04	23.18	21.59	19.62

Developmental	29.07	29.41	28.67	29.98
Parsimonious	27.31	27.17	26.29	26.70
Testable	31.90	31.03	29.31	31.60
Unified	32.69	31.99	31.48	32.75

Note. CNSKS subscale score: Minimum = 8; Maximum = 40; Neural = 24.

Table II. Pretest and Posttest Means of CNSKS Subscale Scores

	Creative			Testable		
	MD	s	t	MD	s	t
Experiment 1	4.14	0.70		-0.87	0.35	-2.46*
Experiment 2	-1.97	0.53	-3.72*	2.29	0.33	6.86*

*p < 0.05; MD = posttest mean score -pretest mean score; s = standard deviation of MD

Table III. Dependent t-test Results for CNSKS Creative and Testable Subscale Scores

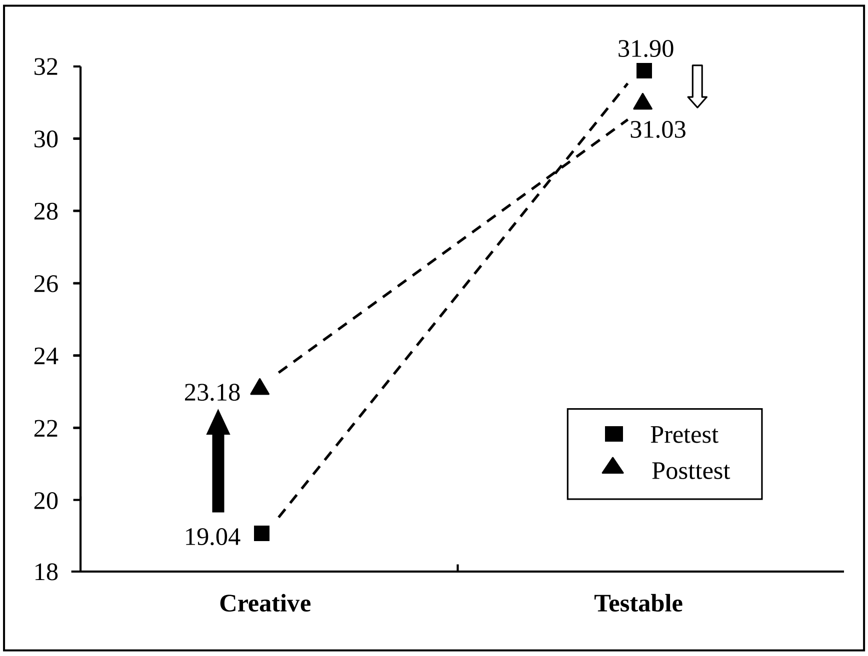


Figure 2. The seesawing movement of creative vs. testable NOS conceptions in Experiment 1

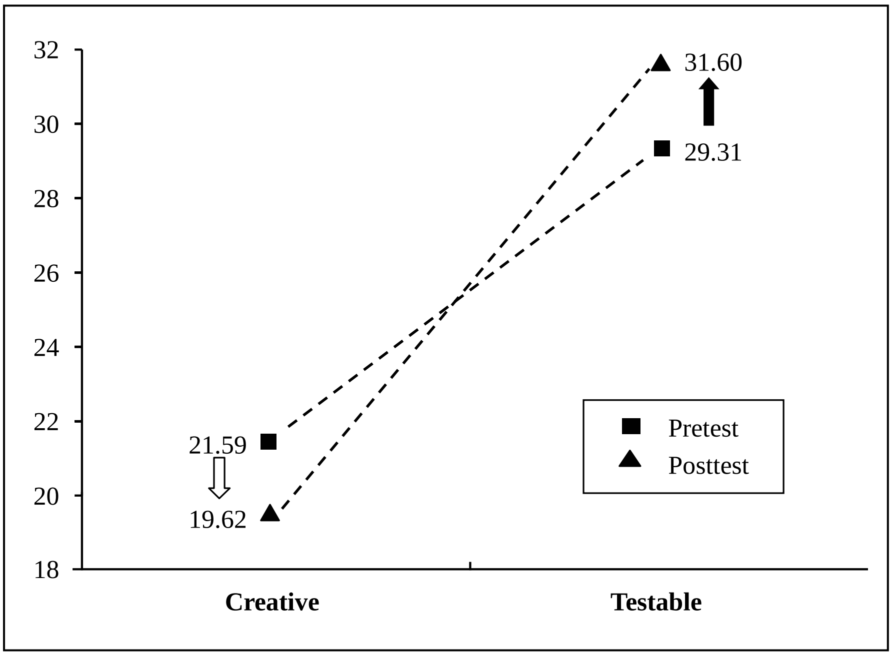


Figure 3. The seesawing movement of creative vs. testable NOS conceptions in Experiment 2

Appendix I: Rubba Model of Scientific Knowledge (Rubba & Andersen, 1978)

Amoral	Scientific knowledge provides man with many capabilities, but does not instruct him on how to use them. Moral judgment can be passed only on man's application of scientific knowledge, not on the knowledge itself.
Creative	Scientific knowledge is a product of the human intellect. Its invention requires as much as creative imagination as does the work of an artist, a poet, or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.
Developmental	Scientific knowledge is never "proven" in an absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be

	judged in their historical context.
Parsimonious	Scientific knowledge tends toward simplicity, but not to the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort in science to develop a minimum number of concepts to explain the greatest possible number of observations.
Testable	Scientific knowledge is capable of public empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.
Unified	Scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contributes to a network of laws, theories, and concepts. This systemized body gives science its explanatory and predictive power.

Appendix II: Galileo and the Moon's New Clothes

In 1611, an Italian man in his late 40s wrote a letter to Kepler, the leading astronomer of Europe at the time, complaining: “You are the first and almost the only person who, after a cursory investigation, has given entire credit to my statements...... What do you say of the leading philosophers here to whom I have offered a thousand times of my own accord to show my studies, but who, with the lazy obstinacy of a serpent who has eaten his fill, have never consented to look at the planets, or moon, or telescope?”

Stop the story here and ask your students the following question. Wait for students’ answers before continuing the story.

Who do you think wrote this letter? Why was he so upset about his contemporary leading philosophers?

The man writing the letter was Galileo Galilei (1564-1642), a famous scientist who lived at the end of the Renaissance. Born in Pisa, Italy in 1564 (the year of Shakespeare's birth and Michelangelo's death), Galileo lived at a time when most leading philosophers followed Aristotle's teaching faithfully and believed that anything that contradicts Aristotelian philosophy must be wrong. In particular, most of his contemporary philosophers believed that the *Earth* was at the center of the universe and that the surfaces of all heavenly bodies - the moon, the planets and the stars - were *smooth, uniform and perfectly spherical*. Although Galileo suspected that they might not be right about this, he did not have enough scientific evidence to disapprove it until 1609 when he constructed his own “home-made” telescope and pointed it toward the heavens.

With the help of his telescope, Galileo found that “...the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the Earth, relieved by chains of mountains, and deep valleys.” This evidence was so directly opposed to the Aristotelian notion of a *perfect* moon that Galileo thought his telescopic discoveries would soon cause everyone to realize how absurd the Aristotelian notions were and abandon them altogether.

To his surprise and disappointment, however, many of his contemporaries refused to accept the scientific validity of his telescopic discoveries and still insisted that the moon was smooth, uniform and perfectly spherical. Some argued that the evidences of the telescope could be due to distortions, citing the fact that all glass lenses were known to change the path of light rays. Others said that even if telescopes *seemed* to work for terrestrial observation, nobody could be sure they worked equally well when pointed at these vastly more distant celestial objects.

One of Galileo's opponents, Colombe, although admitted that the surface of the moon *looked* rugged, maintained that it was actually quite smooth and spherical as Aristotle had said, reconciling the two ideas by saying that the moon was covered with a smooth transparent material through which mountains and craters inside it could be discerned.

Stop the story here and ask the students to analyze the story and consider the following questions about the nature of science raised by the story. Accept all sensible answers and do not indicate whether they are correct or not, for there are no “right” answers.

How and why do you think Galileo and his opponents were able to reach different conclusions based on the same observational data?

Can observation alone give rise to scientific knowledge in a simple inductivist manner? Why do you think so?

How do you think we should decide whose theory is “correct”? Can they both be “correct”? Why do you think so?

Are imagination and creativity important for developing scientific theories? Why do you think so?

Faced with this kind of response from a leading scholar at that time, if you were Galileo, what would be your reply to your opponent's argument about the perfect moon?

Finish the story by presenting Galileo's reply to his opponent's argument.

Galileo (sarcastically applauding the ingenuity of this theory) offered to accept it gladly – provided that his opponent would do him the equal courtesy of allowing him to assert that the moon was even more rugged than he had thought before, its surface being covered with mountains and craters of this *invisible* substance ten times as high as any he had seen. He went on to say: “The hypothesis is pretty; its only fault is that it is neither demonstrated nor demonstrable. Who does not see that this is a purely arbitrary fiction that puts nothingness as existing and proposes nothing more than simple noncontradiction? One might equally well define Earth to include the atmosphere out to the top of the highest mountain and then say ‘the earth is perfectly spherical.’”

Stop the story for discussion. Possible questions include, but are not limited to:

Do you agree with Galileo's criticism of his opponent's theory? Explain why you think so.

What does this story tell us about science and how it progresses? Do you know any other similar case in modern science?

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