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EXPLORING SCIENTIFIC CREATIVITY OF ELEVENTH GRADE STUDENTS IN TAIWAN

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EXPLORING SCIENTIFIC CREATIVITY OF ELEVENTH GRADE STUDENTS IN TAIWAN

by

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Dedication

To my parents, husband, and son

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EXPLORING SCIENTIFIC CREATIVITY OF ELEVENTH GRADE STUDENTS IN TAIWAN

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Although most researchers focus on scientists' creativity, students' scientific creativity should be considered, especially for high school and college students. It is generally assumed that most professional creators in science emerge from amateur creators. Therefore, the purpose of this study is to investigate the relationship between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science for finding significant predictors of eleventh grade students' scientific creativity.

A total of 130 male eleventh-grade students in three biology classes participated in this study. The main instruments included the *Test of Divergent Thinking (TDT)* for creativity measurement, the *Creativity Rating Scale (CRS)* and the *Creative Activities and Accomplishments Check Lists (CAACL)* for measurement of scientific creativity, the *Nature of Scientific Knowledge Scale (NSKS)* for measurement of the nature of science, and the *Science Attitude Inventory II (SAI II)* for measurement of attitudes toward science. In addition, two instruments on measuring students' abilities of problem finding and abilities of formulating hypotheses were developed by the researcher in this study.

Data analysis involved descriptive statistics, Pearson product-moment correlations, and stepwise multiple regressions. The major findings suggested the following: (1) students' scientific creativity significantly correlated with some of selected variables such as attitudes toward science, problem finding, formulating hypotheses, the nature of science, resistance to closure, originality, and elaboration; (2) four significant predictors including attitudes toward science, problem finding, resistance to closure, and originality accounted for 48 % of the variance of students' scientific creativity; (3) there were big differences between students with a higher and a lower degree of scientific creativity on the variables of family support, career images, and readings about science; and (4) many students were confused about the creative and moral levels on *NSKS* and the concept of "almighty of science" and purposes of science on *SAI II*.

The results of this study may provide a more holistic and integrative interpretation of students' scientific creativity and propose better ways of evaluating students' scientific creativity. In addition, the research results may encourage teachers to view scientific creativity as an ability that can be enhanced through various means in classroom science teaching.

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CHAPTER 1

INTRODUCTION

Background of Study

Creativity may be characterized as having two levels (Mansfield & Busse, 1981): One is professional creativity and the other is amateur creativity. Scientists are considered as professional creators because they may make significant and innovative contributions to their areas of specialization. Amateur creators also demonstrate creativity in comparison to their nonprofessional peers. For instance, high school science fair winners or secondary students whose scientific reports were considered unusually creative by their teachers may be characterized as amateur creators. Although most researchers focus on professional creators, amateur creators should be considered, especially for high school and college students, since it is generally assumed that most professional creators in science emerge from amateur creators. Researchers (Parloff, Datta, Kleman, & Handlon, 1968; Ypma, 1968) found that research scientists who conducted scientific experiments on their own initiative in both high school and college were judged to be more creative in their professional work.

A large amount of work has been done in exploring scientists' creativity, whereas few researchers have focused on students' creativity in science. Most major approaches to scientific creativity of scientists have focused on products to identify persons as creative. Many researchers use publications, citation counts, expert ratings, and patent rates as external objective criteria for evaluating creativity of scientists (Musil & Ondrusek, 1982). In addition, intelligence structure tests, divergent thinking tests, cognitive style tests, and questionnaires of creative personality have been internal criteria for evaluating scientific creativity. However, there is much controversy surrounding this issue. First of all, most researchers only use citations in journals, not references in books. In addition, the quality of the cited publications is not considered. Secondly, tests for evaluating creativity are not appropriate tools to evaluate scientific creativity. Musil and Ondrusek (1982) argued that specific divergent thinking tests have to be designed to improve the prediction of specific types of creativity. Some researchers have designed specific tests for assessing students' scientific creativity such as physics creativity tests, mathematics creativity tests, and chemistry creativity tests (Davis, 1971; Eichenberger, 1978). Unfortunately, there are still no scientific creativity tests published for commercial testing.

Some researchers think that scientific creativity is the ability to formulate fresh questions rather than to solve given problems (Getzels & Csikszentimihalyi, 1967; Mackworth, 1965). Therefore, ability of problem finding seems to be close to the heart of originality in creative thinking in science. Snow (1960) distinguishes between problem solvers who are better at solving given problems and problem finders who can formulate new concepts and problems. Many believe that a good problem is often half a discovery, but current mental tests are biased against problem finders because they inevitably favor the problem solvers. Although there has been some research on problem finding in the areas of art, writing, and the ability to formulate questions (Arlin, 1975; Getzels & Csikszentmihalyi, 1967, 1976; Moore, 1994), there has been little research on problem finding in science.

Fredericksen (1984) suggested that formulating ill-structured problems may be analogous to hypotheses generation and testing. In addition, Hoover (1992) defined the ability of problem finding as the subjects' abilities to formulate hypotheses in a given realistic scientific situation. In Hoover's study, there were significant correlations between a measure of creativity and the ability of formulating hypotheses among gifted fifth-grade students. As for Subotnik and Steiner's (1994) longitudinal study in Westinghouse Science Talent Search winners, there were no significant differences among three groups: problem finders, presented problem solvers, and non-researchers and their success on the Formulating Hypotheses Test. The result of Subotnik's research seems to indicate the lack of a positive correlation between the ability of problem finding and the ability of formulating hypotheses.

Accordingly, a controversial question arises in these studies. Is the ability of problem finding in science equivalent to the ability of formulating hypotheses in science? Are they totally different abilities? As a matter of fact, problems may exist even before formulating hypotheses, especially in general science teaching situations. In other words, teachers usually give students problems and then let students formulate hypotheses. However, although the ability of problem finding is a very important factor in creativity research, the ability of problem finding is not synonymous with scientific creativity. In addition, it is necessary to determine if other significant factors affect students' scientific creativity.

Nowadays, the approach in assessing students' scientific creativity is almost the same as the approach in assessing scientists' scientific creativity. For instance, some schools use only IQ tests, or academic tests especially in science content knowledge, or performance in a science fair to evaluate if some students have potential scientific talents. Also, research on students' scientific creativity has received little attention. Therefore, this study is aimed at a more sophisticated understanding of the nature of students' scientific creativity, determining significant predictors of students' scientific creativity, and using a multiple and more holistic approach to assess students' scientific creativity.

Rationale and Theoretical Base

There are two conceptual models for identifying creative talent in this study. The first one is based on the work of Mooney (1963), who proposed to use a fourfold classification of creativity: the creative product, the creative person, the creative process, and the creative environment for exploring creativity. Each of these four aspects offers a different approach and criteria for the identification of creative talent. These four approaches are not only different from each other but also may tend to be against each other. For example, the administrator's interest in products may threaten a creative producer. Thus, it is necessary to take hold of all these perspectives at once so that each can serve and support rather than threaten the others. Mooney suggested that it is necessary to put the four approaches together by showing them to be aspects of one unifying idea.

Mooney used a conceptual model, essential conditions for the existence of man, (Figure 1) to interpret how these four approaches bond together. A broken circle represents the universe (Figure 1a), and the breaks provide a way toward infinity. There are a multitude of energy forms like "rocks, seas, air, earth, tides, winds, animals, vegetables, minerals, atoms, molecules, etc. within the universe" (p.334). The small circle represents an individual man placed inside the universe (Figure 1b). Everything we do is synchronous within the whole system. For

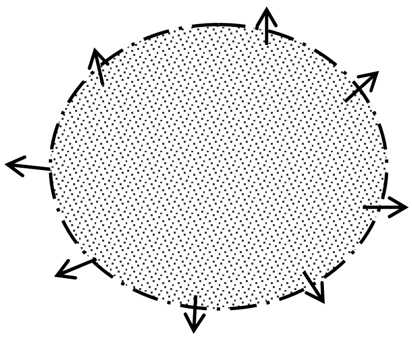

Figure 1a. Composition within universe: energy forms in action.

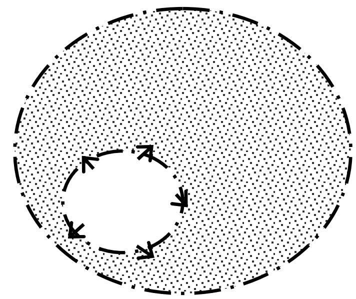

Figure 1b. A man's outward relation to other energy forms.

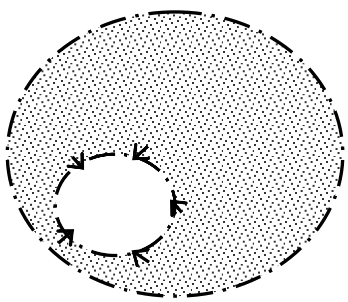

Figure 1c. A man's inward relation from other energy forms.

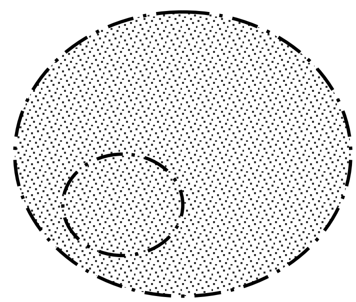

Figure 1d. Composition within man: energy forms in action.

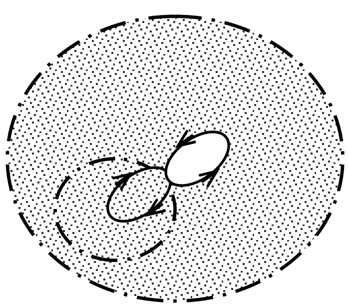

Figure 1e. A man's sequential transaction with other forms.

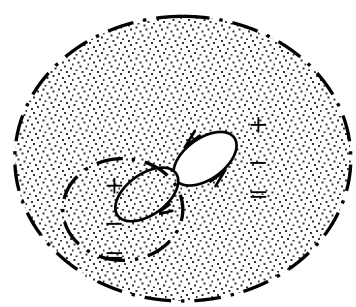

Figure 1f. A man's selective fitting During transaction.

Figure 1. A conceptual model: essential conditions for the existence of man (from Mooney, 1963).

symbolizing this relation, Mooney used outgoing arrows account for the first (the environment) of the four essential conditions for the existence of man. However, not only a man does extend outward toward the universe, but also the universe comes in toward a man as well. A man perceives the universe, acts in it, organizing it, and comprehends it. Thus, Mooney draw arrows from the universe into the circle of man (Figure 1c) to account for the second (the person) of the four essential conditions for the existence of man.

Inside the circle of man, it is necessary to take in usable energy forms from outside while energy forms are transformed and expended from inside. This sequential and ordering flow is symbolized by drawing an arrowed infinity sign between inside and outside (Figure 1e). This sign suggests the third (the process) of the four essential conditions for the existence of man. However, this kind of activity involved reaching-out and receiving-in on the infinity sign needs to be selective. There are three selective operations represented in Figurer 1f, and "these three symbols to denote three basic choices --- inclusion of the needed (+), exclusion of the damaging (−), and tolerance of the remainder (=)" (p.337). These three symbols at the ends of the infinity sign declares man's selection and his continuous fitting of specific incomings and outgoings. This represents the fourth of the four (the product) essential conditions for the existence of man. In summary, these four dimensions are fundamentals of "logic of life" to Mooney.

For further studies, Mooney asked artists to tell him "what they must have in their particular expression of the basis for a living creation." The dramatists said that the elementary conditions are (1) a setting, (2) actors, (3) action, and (4) the play. Painters said that the elementary conditions are (1) ground, (2) figure, (3) tension, and (4) the painting. To Mooney, life is in everywhere, whether it is in perception, in biology, in highly creative experiences like arts, cultural development, and psychology, and in learning. The same thought model emerges from similar elementary conditions. Therefore, Mooney turned the same conceptual model into scientific creativity to find a deeper ground for identifying creative scientific talent.

The second model is based on the work of Amabile (1983) who proposed a three-component model by using a more social psychological approach to creativity. As shown in Table 1, Amabile's creativity consists of three components: domain-relevant skills, creativity-relevant skills, and task motivation. Domain-relevant skills are the most basic, because one cannot be truly creative unless one knows a great deal about a particular area and has the skills necessary to produce in that area. Creativity-relevant skills are cognitive and personality characteristics that have traditionally been viewed as underlying generation of potentially creative responses. Task motivation includes attitudes toward the task and perceptions of own motivation for undertaking the task.

1 Domain-Relevant Skills	2 Creativity-Relevant Skills	3 Task Motivation
Includes: Knowledge about the domain Technical skills required Special domain-relevant "talent" Depends on: Innate cognitive abilities Innate perceptual and motor skills Formal and informal education	Includes: Appropriate cognitive style Implicit or explicit knowledge of heuristics for generating novel ideas Conducive work style Depends on: Training Experience in idea generation Personality characteristics	Includes: Attitudes toward the task Perceptions of own motivation for undertaking the task Depends on: Initial level of intrinsic motivation toward the task Presence or absence of salient extrinsic constraints Individual ability to cognitively minimize extrinsic constraints

Table 1. Components of creative performance (from Amabile, 1983).

In fact, Renzulli's (1978) conceptualization of giftedness includes each of Amabile's three basic components: above average general ability and knowledge (domain-relevant skills), a high level of task commitment or motivation, and a high level of creativity-related skills. As shown in Figure 2, giftedness is composed of three clusters, and there is interaction represented by the shaded portion of Figure 2 among the three clusters. Renzulli pointed out that that each cluster is an "equal partner" on contributing to giftedness. Based on Renzulli's theory, a new research-based and operational definition of the gifted and talented is offered to help the practitioner.

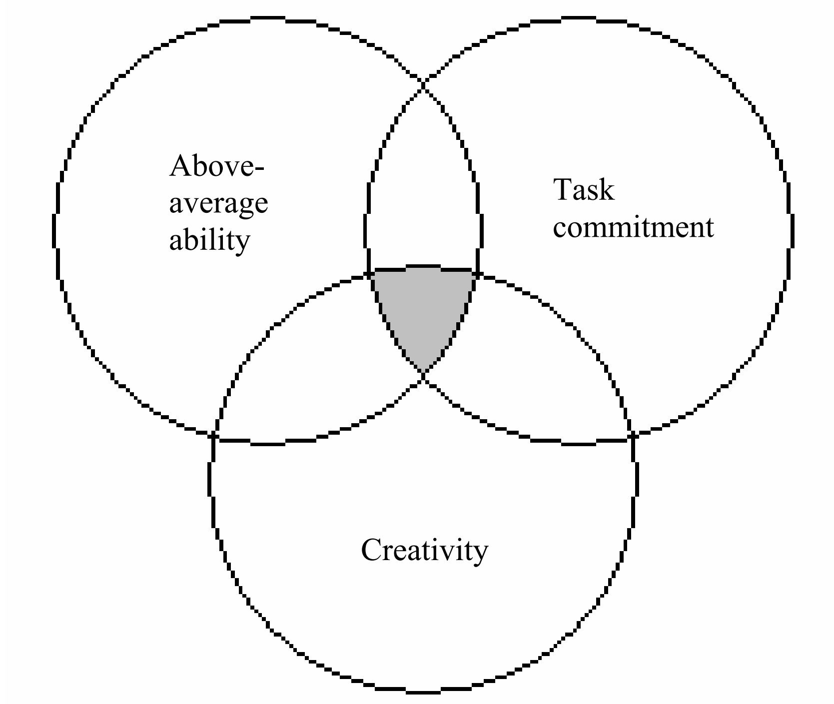

Figure 2. The ingredients of giftedness (from Renzulli, 1978)

According to these models and previous literature on scientific creativity, some variables such as creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science were selected in this study. This study provides a more holistic and integrative approach to assess students' scientific creativity rather than science achievement tests or a single performance in a science fair. To explore students' scientific creativity is not just for sending or identifying students with creative potential for special programs. Rather, the results of the research may help teachers understand that scientific creativity can be encouraged through various means in classroom science teaching.

Statement of the Problem

What are significant predictors of scientific creativity among eleventh grade science students in Taiwan?

Purpose of the Study

The purpose of this study is to explore the correlation between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Correlations among scientific creativity and these variables may help to understand the nature of students' scientific creativity and determine significant predictors of eleventh-grade students' scientific creativity in the process of learning science.

Research Questions

The major research questions to be addressed in this study are as follows:

1. Are there significant correlations among scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, attitudes toward science in the process of learning science by eleventh-grade students?
2. What are significant predictors of scientific creativity in the process of learning science by eleventh-grade students?
3. Are students with a higher degree of scientific creativity different from those students with a lower degree of scientific creativity on variables such as family support, career images, readings about science, role models, and parents' expectations?

Assumptions

The assumptions of this study are as follows:

1. Since peer nomination was used in this study, it is assumed that students are very familiar with their peers in class. Therefore, they can make fair and reliable judgments.

2. Since all subjects in three different classes were taught by the same biology teacher, it is assumed that they obtained similar attention, instructions, and tests from the biology teacher.

Importance of the Study

Nowadays, science educators realize that creativity plays a major role in the science enterprise and science teaching; unfortunately, few researchers have focused on exploring students' scientific creativity and improving or fostering students' creativity in science learning. Therefore, both theoretical and pedagogical significance will be pursued in this study. Theoretically, this study attempts to determine correlations between scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. The research results may help determine significant predictors of scientific creativity and eventually find more appropriate ways to evaluate students' scientific creativity. Also, the research results may help us to use a more holistic and integrative approach to assess students' scientific creativity.

Of pedagogical significance, if the findings of this study show a strong correlation between scientific creativity and some of the variables, science teachers may view scientific creativity as an ability that can be taught rather than an innate, insightful, or fantastic ability. The research results will help teachers understand better which factors may affect students' scientific creativity most. Therefore, scientific creativity can be enhanced through various means in classroom science teaching.

Definitions of Terms

Creativity

Creativity involves divergent thinking namely the ability to generate multiple, disparate, and unusual ideas in response to a problem (Guilford, 1967). Creativity means a person's capacity to produce new or original ideas, insights, restructurings, inventions, or artistic objects, which are accepted by experts as being of scientific, aesthetic, social, or technological value (Vernon, 1989). Creativity as the process of sensing difficulties, problems, gaps in information, missing elements, something askew; making guesses and formulating hypotheses; possibly revising and retesting them; and finally communicating the results (Torrance, 1988).

Scientific Creativity

Scientific creativity may be view as the attainment of new and novel steps in realizing the objectives of science. Scientific creativity can manifest itself "in the conception of new ideas contributing to scientific knowledge itself, in the formulation of new theories of science, in the devising of new experiments to probe nature's law, in the development of scientific ideas applied to particular domains of practical interest, in the realization of new organizational features of scientific research and of scientific community, in the novel implementation of plans and blueprints for scientific activities, in trail-blazing undertakings to transmit the scientific outlook into the public mind, and in many other realms" (Moravcsik, 1981, p.222).

Problem Finding

Mackworth (1965) stated that problem finding is the detection of the need based on a choice between existing and expected situations. Mackworth considered problem finding resulted in the discovery of many general questions (discovered problems) from many ill-defined problems situations. Getzels (1975) stated that problem finding is the way problems are envisaged, posed, formulated, created. Problem finding results from an effort to utilize both specific and general problem-solving procedures as an attempt is made to integrate new data, experiences, or information into an organized memory structure. (Hoover & Feldhusen, 1994).

Formulating Hypotheses

Formulating hypotheses consists of those mental activities that yield a tentative explanation of a problematic situation. The chief function of the generation component of scientific inquiry is to provide the investigator with only plausible hypotheses (Rachelson, 1977). Generating hypotheses is a type of problem solving in which the initial state consists of some knowledge about a domain, and the goal state is a hypothesis that can account for some or all of that knowledge in a more concise or universal form (Klahr, 2000).

Nature of Science

A consensus view of the nature of science objectives is extracted from eight international science education standards documents. Scientific knowledge has a tentative character; scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, and rational arguments; there is no one way to do science; science is an attempt to explain natural phenomena; laws and theories serve different roles in science; people from all countries contribute to science; new knowledge must be reported clearly and openly; scientists require accurate record keeping, peer review, and replicability; observations are theory-laden; scientists are creative; the history of science reveals both an evolutionary and revolutionary character; science is part of social and cultural traditions;

science and technology impact each other; scientific ideas are affected by their social and historical milieu (McComas, Almazroa, & Clougii, 1998).

Attitudes toward Science

Attitude toward science addresses scientific attitudes, attitudes toward scientists, attitudes toward scientific careers, attitudes toward methods of teaching science, scientific interests, attitudes toward parts of the curriculum, or attitudes toward the subject of science (Haladyna & Shaughnessy, 1982).

Delimitations of the Study

Delimitations set the boundaries under the study. The delimitations of this study are as follows:

1. Subjects were 130 eleventh-grade male students with science majors enrolled in a senior high school in northern Taiwan.
2. Generally speaking, research of scientific creativity was divided into four classifications: product, process, person, and environment. Because the environment variable is too complex and the process variable needs to be followed in a longitudinal study, this study just focused on products and personality classifications of scientific creativity.

3. The study was conducted in a biology class. Therefore, the ability of problem finding and the ability of formulating hypotheses were related to the biology field.
4. The study focused on scientific creativity, creativity, the ability of problem finding, the ability of formulating hypotheses, science achievement, knowledge about the nature of science, and attitudes toward science; it did not focus on cognitive learning styles.

Summary

Creativity plays a major role in the science enterprise and science teaching, but few researchers have focused on exploring students' scientific creativity and ways to improve or foster students' creativity in science learning. Methods to enhance scientific creativity may be implemented not only at a college or postgraduate levels, but also in elementary and secondary school education. It is only the technical content of science that changes from elementary school to a Ph.D. curriculum. The spirit of science as a method of inquiry remains unchanged from the time a child asks the first "Why" through when a prominent scientist wins the Nobel Prize. This chapter has identified the purpose of this study as exploring the correlations between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Based on these correlations, it is possible to determine the most significant predictors of students' scientific creativity. The background, statement of the problem, theoretical base, assumptions, statement of hypotheses, and limitations are also presented.

Chapter Two presents an overview of related research on scientific creativity and related variables which is reported in the following sequence: 1. creativity; 2. scientific creativity; 3. problem finding; 4. formulating hypotheses; 5. the nature of science; 6. attitudes toward science. In addition, supporting research is also included in this chapter.

Chapter Three delineates the research methodology employed in this study. Research design, sampling and site description, instrumentation, data collection and data analysis procedures are included in this chapter.

Chapter Four presents the results of the investigation with statistic analyses. Results are presented in the forms of tables and figures.

Chapter Five delineates a summary of the findings, draws conclusions based on the findings, discusses the results and conclusions of this study, addresses the implications of educational application and practice, and makes suggestions for curriculum, instruction, and future research in science teaching in high schools. The related bibliography is provided at the end of this dissertation.

CHAPTER 2

LITERATURE REVIEW

Creativity

Theories of Creativity

One of the most popular cognitive theories of creativity is Guilford's divergent production theory (Guilford, 1967). Guilford grouped the 16 divergent production factors that were categorized into four classifications: fluency, flexibility, originality, and elaboration. Fluency is the ability to produce a large number of ideas. Flexibility is the ability to produce a wide variety of ideas. Originality is the ability to produce unusual ideas. Elaboration is the ability to develop or embellish ideas, and to produce many details to flesh out an idea. Since the Torrance Tests of Divergent Thinking dominate the field of creativity research, divergent thinking has become almost synonymous with creativity. It is generally accepted that divergent thinking is considered as a kind of shorthand for creativity.

The theory of associative process different from divergent thinking is to use the concept of combination to approach creativity. (Mednick, 1962). In Mednick's view, a creative idea results from the novel combination of two or more ideas that have been away from their normal correlations. In other words, creativity is a function of people's associative hierarchy that is the way they produce associations to words or problems. In addition, Weisberg (1986) claimed that creativity occurs through a series of small steps in which earlier ideas are modified and elaborated. The nature of creativity occurs when the problem solver runs into obstacles, proposes solutions, runs into further obstacles, and then refines and elaborates the earlier solutions. In contrast to the perspective of creativity as incremental problem solving, some researchers have reemphasized to importance of problem finding (Getzels & Csikszentmihalyi, 1976; Runco & Okuda, 1988).

One suggestion is that creativity involves not just representing a given problem, but also finding the real problem and representing it. Creative people may not be creative in their solutions but rather creative in their choices of problems. In a unique longitudinal study of prospective artists, Getzels and Csikszentmihalyi (1976) found that problem finding had at least short-term criterion validity as one element of artistic creativity. They suggested that low scorers in problem finding adopted a known solution, whereas high scorers in problem finding attempted to discover something new. In fact, problem solving and problem finding are not mutually exclusive. Rather, they have different emphasis but similar processes and frameworks. Combining these two views, creativity is considered as arising from a great deal of refining, elaborating, and reformulating of the problem and its possible solutions. Some researchers in recent years used the creative cognition approach to provide a thorough analysis of creativity (Ward, Smith, & Finke, 1999). They claimed that creativity is the result of many types of mental processes working together and they believed that it is important to construct global information-processing models that can capture a variety of creative thought rather than focus on only a single type of creativity.

Generality of Creativity

In the field of creativity, many researchers and theorists have treated creativity as a general intellectual trait that will affect a person's performance regardless of the particular activity in which they happen to be engaged (Hennessey & Amabile, 1988; Tardif & Sternberg, 1988; Trefinger, 1986). However, creativity has been viewed as something beyond domain-dependent knowledge and skills in both conventional wisdom and most creativity theories. Creativity as a general skill or trait has been defined in many ways: habits of thoughts, attitudes, personality traits, or skills in the use of problem solving heuristics (Darley, Glucksberg, & Kinchla, 1986). The most influential one of these general creativity relevant factors or theories has been the theory of divergent thinking. It is typically assumed that divergent thinking skills are easily transferable from one task to another.

Hocevar (1976) and Runco (1987) used self-report questionnaires to assess the generality of creativity. Hocevar reported a high degree of generality of creativity in the self-reported creative performance of college students, but Runco found low correlations among the quality of creative performances of fifth through eighth-grade students in different domains. In a later study, Runco (1989) had artists rate three different art projects on elementary students. Inter-item correlations ranged from –0.10 to 0.29 indicating little generality of creative performance even within the domain of art. Accordingly, it is difficult to deny that domain-relevant skills and knowledge also have been acknowledged to be important contributors to creativity. Thus, many researchers contended that creativity is domain-specific.

Domain specificity is supported most by Gardner (1983). Gardner argued that cognition must be decomposed to a number of parts or factors as proposed that there are at least seven different intelligences, each of them has its own set of rules. According to Gardner's theory of multiple intelligence, we should not speak of an individual as creative, but we should speak that one would recognize the possibilities of creativity in specific domains. In domain specificity theory, domain-relevant skills and knowledge were received much attention. For example, it is generally accepted that scientific discoveries do not occur by sudden insight. Rather, scientific creativity requires background knowledge and domain skills. Therefore, to clarify what kind of the role knowledge plays in affecting scientific creativity performance may explain the relationship between creativity and scientific creativity. Knowledge in science domain may include science content knowledge itself and knowledge about the nature of science.

Intelligence, Knowledge and Creativity

Early research confirmed that creativity and intelligence are different cognitive capacities (Getzels & Jackson, 1962; Wallach & Kogan, 1965). Torrance (1963) supported this finding by saying that "no matter what measure of IQ is chosen, we would exclude about 70% of our most creative children if IQ alone were used in identifying giftedness" (p.182). Additionally, some researchers suggested creativity as a subset of intelligence. For instance, Guilford (1967) indicated that the facets of his model of intelligence involve creativity (divergent production) that was not measured by conventional tests of intelligence. Also, Gardner (1983) treated creative functioning as one aspect of the multiple intelligences.

In contrast, some researchers emphasized that intelligence can be viewed as a subset of creativity. For example, Sternberg and Lubart (1995) argued that there are six main elements that converge to form creativity: intelligence, thinking styles, personality, motivation and the environment. However, the most conventional view is that intelligence and creativity overlap in some ways, but not in others. People with high intelligence probably have a unique potential for creative productivity. In other words, high intelligence may be a strong clue for identifying high creative potential.

The tension between creativity and knowledge has been received much attention. Weisberg (1999) claimed that one must have knowledge of a field if one hopes to produce something novel within it, but sometimes too much knowledge will let one get in ruts and cannot go beyond stereotyped solutions. Weisberg considered the relationship between knowledge and creativity as a U shape, so the maximal creativity occurs with some middle range of knowledge. In addition, Tang (1986) suggested that broad knowledge may enhance scientific creativity. Tang emphasized that a broad background in several scientific fields may increase the creative powers of scientists because it will allow them to make novel connections.

Measurements of Creativity

Generally speaking, we use tests, inventories, rating scales, affective characteristics, or the innovative products to evaluate creative abilities. Tests and inventories are treated as more formal identification procedures because they have more objective test scores. For instance, there are two main categories of creativity tests: divergent thinking tests and personality inventories (Davis, 1997). The Torrance Tests of Creative Thinking (TTCT) is the most popular creativity test battery and also have most complete scoring guides, norms, and longitudinal validity (Torrance, 1962, 1990; Torrance & Wu, 1981). According to Torrance (1977), the figural forms of TTCT are more culture-fair.

As for personality inventories, My How Do You Think (HDYT) test (Davis, 1975) is used to determine creative personality, and some researchers supported its construct and criterion-related validity. The Group Inventory for Finding Interests II (GIFFI II) is a simple and published version of HDYT for high school students; GIFFI I is special for middle school students (Davis & Rimm, 1982). In addition, self-reported procedures in creative activities and past creative achievements both are solid predictors of present and future creativity, even though they are classified as more informal and subjective identification procedures (Davis, 1989; Holland, 1961). In fact, several subjective procedures such as information regarding students' past and present creative activities may have higher validity.

Finally, a large portion of the research on creativity takes place in educational settings, so teacher ratings are a commonly used criterion of creativity. Yamamoto (1963) first established standards for teachers to use in their ratings, and Yamamoto's work is illustrative of the approach taken by several researchers. These standards involve identifying the most and the least creative thinkers in the class. The creative thinking was defined as fluency (lots of ideas), flexibility (many different ideas), inventiveness (inventing and developing ideas), originality (unique ideas), and elaboration (detailed ideas). Also, Renzulli's (1983) ten-item creativity rating scale, part of his scales for rating the behavior characteristics of superior students, is used by teachers to rate the students' creativity at any age. This scale appears to be the best one of the nomination forms (Ashman & Vukelich, 1983) because its carefully assembled contents compare well with other descriptions of the creative personality.

The majority of educators agree that students with high creative potential should be identified for special programs, but there are still some critics that creativity cannot be measured by currently available creativity tests. In order to make reliable judgments, Davis (1997) suggested that the results of the creativity test should be combined with other information regarding students' creativeness. In other words, at least two criteria should be used together to evaluate students' creativity such as divergent thinking tests and personality inventories, or either of them and teachers', parents', or peers' ratings of creativeness.

Nature-Nurture in Creativity

The nature-nurture topic received very little discussion because of its complexity and difficulties of collecting objective evidence. Generally speaking, genius is affected by environment, upbringing, the genes, and personality factors (Vernon, 1989). As Vernon said, nature and nurture are not opposed factors but are complementary to each other. The genes may control or modify the environment, as when a highly intelligent child shapes his own environment by choosing books to read and other intellectual activities. In the other hand, environmental stimulation may bring about neurological growth. That is, the causation between nature and nurture is not necessarily one way (Vernon, 1979). As educational researchers, environmental stimulation has to receive more credits since the educational system has a responsibility to build an appropriate environment to enhance students' creativity in various fields.

Some researchers suggested that children from birth to age 7 have far more synaptic connections than older children and adults (Siegler, 1994). In other words, younger children can have higher variability and make novel connections more easily. Therefore, that the older we are, the less creative we become seems to be a very good excuse for some adults to have low creativity. However, the interesting problem is how creative individual in specific domains performs better than other peers, and what kind of stimulus makes creative individual produce more synaptic connections when they have great discoveries such as ideas combination. These questions will be considerable issues in neuropsychology for exploring biological bases of creativity in the future.

Scientific Creativity

Although creativity has been actively studied by psychologists for many years, there are relatively few studies on creative scientists and only small number on scientists within any specific field or domain (Mansfield & Busse, 1981). In scientific creativity field, most researchers focused on creative thoughts, products, and processes of scientists, whereas few researchers focused on students' creativity in science, especially for secondary school students. Boden (1994) distinguished between historical creativity and personal creativity. Historical creativity is considered as the discoveries made by scientists who constitute historical occasions when new knowledge was established for the whole culture. For example, Newton's description of the solar system as a central force system was historical creative. Personal creativity is the generation of a novel idea for an individual, even if that idea has been had by someone else. From the standpoint of psychology, personal creativity is important because it reflects the operation of processes that lead to new ideas.

Getzels and Csikszentmihalyi (1967) contended that scientific creativity is the ability to formulate fresh questions rather than only solve given problems.

They suggested that there are different types of problem situations such as presented problem situations and discovered problem situations requiring different kinds of thoughts. The discovered problem situation seems like the problem itself remains to be discovered. Some problem solvers, like artists and scientists, do not wait for others to pose the task of identifying problems but are sensitive to identifying unformulated problems themselves. Einstein and Infeld (1938) claimed that "the formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skills. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science (p.83)." According, discovery of new problems is often defined as the unique character of creativity in science.

A large amount of work done in the field of scientific creativity is to use productivity to assess scientific creativity. To reduce the subjective element creative products, two broad classes of methods have been developed: citations counts and expert ratings. The citation count method is not new, but the use of databases such as the Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) has made it more powerful in recent years. However, the counts based on the SCI and SSCI have some weakness as described in Endler (1987). Some of these limitations are that only citations in journals, not references in books; quality of the cited publication is not considered; the counts are biased against authors publishing in language other than English. In addition, it is impossible to use publications, citation, research grants, and so on to identify students' scientific creativity. If we try to use creative products to assess students' scientific creativity, it should be involved a portfolio-like assessment rather than just a single product.

Many researchers used different views such as historical and cognitive-historical views to explore the process of scientists' creativity. According to historical views, researchers analyzed scientists' whole lives to understand how scientists find problems and new concepts. For instance, Holmes (1985) used "content analysis" to present a detailed analysis of Lavoisier's work. He used Lavoisier's laboratory notebooks, folded sheets, and manuscripts to trace his mental steps and the emergence of his theories. According to cognitive-historical views, researchers analyzed the conceptual changes and reasoning processes of scientists. For example, Nersessian (1993) analyzed scientists' thinking with analogical reasoning, imagistic reasoning and thought experiments. Cognitive-historical analysis attempts to enrich historical examinations by means of investigations of ordinary human representational and problem-solving practices carried out by the sciences of cognition.

Two Conceptual Models for Identifying Scientific Creativity

I. Creative product, process, person and environment:

Generally speaking, scientific creativity research was divided into fourfold classification: the creative product, the creative process, the creative person and the creative situation (Mooney, 1963). The creative product and the creative process have typically been seen as the criteria of creativity. As for creative product, researchers usually use citation counts (SSCI or SCI) and expert ratings to evaluate creative products in science. In addition to citation counts, rating of the scientific quality of a publication by experts is another tool for identifying scientific creativity (Heinrich, 1995). Although such ratings are done informally, this kind of approach improves the validity of assessments involved citation counts.

One of the most comprehensive theoretical models to judge creative products is *Creative Product Analysis Matrix* (Besemer & Treffinger, 1981). The model includes 14 criteria which subsumed in three dimensions: novelty, resolution, elaboration and synthesis for evaluating a product. Based on this model, Besemer and O'Quinn (1986) developed a rating inventory, the *Creative Product Semantic Scale* (CPSS). Two similar instruments (Eichenberger, 1978; Taylor & Sandler, 1972) were specially developed for the field of science, but they have not been widely used by researchers.

As for creative process, Mansfield and Busse (1981) addressed five stages of creative process in science fields. These five stages are: (1) the selection of the problem: sensitivity in the selection of research problems is a primary factor differentiating creative scientists from less creative ones. (2) extended efforts to solve the problem: in the case of a major discovery, there is almost always an extended period of persistent effort before a solution begins to emerge. (3) setting constraints: three types of constraints are empirical, theoretical, and methodological constraints. The working hypotheses must conform to all relevant empirical findings, and the methodology used must be able to prove a solution. (4) changing constraints: working hypotheses may be discarded because new discovered data make them untenable. (5) verification and elaboration: the process of formulating new constraints and testing them is repeated by successive approximations until the scientist constructs a set of constraints leading to an acceptance solution.

In addition, Tardif and Sternberg (1988) suggested that a creative process involves an active search for gaps in existing knowledge, problem finding, or attempting to break through the existed boundaries and limitations. Hence, when students explore in science learning, to find higher-level problems and to formulate adequate and precise hypotheses with both higher quality and larger quantity may be the most considerable part in scientific creative process and products.

In the whole creative process, thought experiments will shed some light in the issues of selection of the problem and formulating hypotheses. In fact, all experiments in their initial stages are thought experiments that play a major role in science education by facilitating conceptual changes and in relation to some types of practical work. A thought experiment is an experiment that proposes to achieve its aims without the benefit of execution. According to Sorensen (1992), a thought experiment has three stereotypical features: first, it makes extensive use of mental imagery, and it involves a high level of cognitive engagement. Second, it is often bizarre in the fanciful settings. Third, it is physically autonomous with no laboratory equipment involved. In addition, Reiner (1998) suggested that any thought experiment has six elements. First, it involves the posing of question or hypothesis. Second, it involves creation of an imaginary world. Third, the thought experiment is designed. Fourth, it is mentally conducted by the thought experimenter. Fifth, an outcome to the thought experiment is produced with the use of the laws of logic. Sixth, a conclusion is drawn.

As for creative person, the creative person has been the main basis of the predictors in creative activity. Descriptions of the creative person typically fall into three general categories: cognitive structure, personality and motivation, and special events or experiences. (Tardif & Sternberg, 1988) First, it is generally acknowledged that people are creative within particular domains. For instance, someone may be a creative chemistry, but he may be a very uncreative novelist. Thus, domain specificity and domain knowledge is a considerable factor when describing cognitive structure. In other words, people have to use existing knowledge in the domain as a base to create new ideas. In scientific creative activity, it is very considerable to understand the role of knowledge in students' scientific creativity. Knowledge in this study not only involves science content knowledge itself but also knowledge about the nature of science. To understand students' development about their understanding of the nature of science has been a long-term concern of science educators (Hogan, 2000). Nowadays, understanding the nature of science is a central component of national science education reform efforts. No researchers' study focused on studying the relationship between understanding the nature of science and performance of students' scientific creativity. For instance, students with 'science is tentative knowledge' belief might have a better performance in scientific creativity than students with 'science is some fact knowledge' belief. Thus, it is a considerate issue to find the relationship between understanding of the nature of science and students' scientific creativity.

Although it is generally agreed that creative individuals are creative within limited domains, various explanations have been offered. Researchers attribute such specificities to inborn sensitivities, combination of intelligence, or highly practiced skills to particular types of information. Tardif and Sterberg (1988) listed some cognitive characteristics that are shared by creative persons. They are originality, imagination, think metaphorically, independence of judgment, coping well with novelty, internal visualization, finding order in chaos, using wide categories, preference of nonverbal communication, building new structures rather than using existing structures, often asking “why”, and being alert to novelty and gaps in knowledge.

As a matter of fact, there is no one personality or motivational characteristics that is useful for attaching the label “creative” to a particular person. Rather, creative personalities are composed of numerous characteristics, some of which may be present in one creative individual, but not in another. The most commonly mentioned characteristics include perseverance, curiosity, being open to new experiences, discipline and commitment to one’s work, high intrinsic motivation, tolerance for ambiguity and so on (Hennessey & Amabile, 1988; Simonton, 1988).

With regard to motivation, intrinsic motivation usually receives much attention because many researchers claimed that motivation makes a strong link to creativity. Duke (1972) argued that there is the most important relationship between intrinsic motivation and creativity. In the process of students' science learning, intrinsic motivation is actually derived from the positive attitudes toward science. For instance, if students enjoy studying science or want to be scientists in the future, they will have strong intrinsic motivation to science learning. Thus, to understand students' attitudes toward science including interests in science, attitudes toward scientists, and attitudes toward scientific careers (Haladyna & Shaughnessy, 1982) may play a key role in exploring students' scientific creativity.

As for special events or experiences, Mansfield and Busse (1981) summarized some studies about child-rearing influences on creativity in science. They divided child-rearing influences into three sections: (1) the parent-child interaction: parental autonomy fostering, parental control, quantity of parent-child interaction; (2) parental characteristics: parental child-rearing values, parental interests; (3) family characteristics: birth order, parental absence, social class. In addition, some researchers suggested that having a future career image, definite role models, mentors, paragons, family interest, family's support, friends' effect, achievement motivation, science anxiety, environment and climate in science class, science teacher, and science curriculum are important factors influencing the development of creators in many fields (Tardif & Sternberg, 1988; Simpson & Troost, 1982).

II. domain-relevant skills, creativity-relevant skills, and task motivation:

Amabile's (1983) componential conceptualization of creativity was one of the first and most influential models in determining performance of creativity. The first component, domain-relevant skills, lays the foundation on which any creative performance must be built. This component includes familiarity with factual knowledge of the domain, technical skills, and special talent in the domain. This set of skills depends upon innate cognitive abilities, innate perceptual and motor skills, and formal and informal education in the domain of endeavor. The second component, creativity-relevant skills, includes a cognitive approach to look at problems from new perspectives, a willingness to explore new cognitive pathways, conductive working style and personality characteristics. These skills depend on training, experience in idea generation, and personality characteristics.

The third component, task motivation, has two basic elements: the individual's baseline attitude toward the task and individual' perceptions of own motivations for undertaking the task. The first element is formed simply "when the individual performs a cognitive assessment of the task and the degree to which it matches his existing preferences and interests”. The second element depends largely on external social and environmental factors, especially in the presence or absence of salient extrinsic constraints in the social environment. It is definite that extrinsic constraints will impair intrinsic motivation and have important influence on creative performance. In sum, Amabile claimed that task motivation is the most important determinant of the difference between what a person can do and what he will do. ‘What a person can do’ is determined by the level of domain-relevant and creativity-relevant skill and ‘what a person will do” is determined by these two skills with an intrinsically motivated state.

Tests for Scientific Creativity

Students with high scores in divergent thinking tests (formal creative tests) may not have high creative potential in science since general creativity should not represent the creativity in specific field. For example, Musil (1982) claimed that specific divergent tests have to be designed in order to improve the prediction of specific types of creativity. Accordingly, we cannot test scientific creativity by only using standard creativity tests. Thus, some researcher tried to design some specific tests for assessing students’ scientific creativity such as physics creativity tests, math creativity tests, and chemistry creativity tests (Eichenberger, 1978; Davis, 1971). Eichenberger used The Judging Criteria Instrument to evaluate creativity in physics class, and he used rating scales to evaluate fluency, flexibility, originality, elaboration, usefulness, social acceptance, and worth to science. Majumdar (1975) used Scientific Creativity Test with 29 subtests from physics, chemistry, biology, and mathematics at the higher secondary level to evaluate students' scientific creativity. Unfortunately, there are still no scientific creativity tests published for commercial testing. Thus, it seems scientific creativity cannot assess by just using a single test, and we need to build a model of assessment involved more holistic elements.

The Creative Activities Check Lists is the most popular instrument for assessing creativity in specific domain, and also it is often used to assess the creative performance of children (Runco, Noble, & Luptak, 1990). Typically, creativity tests are often thought to estimate mere potential rather than actual performance. Accordingly, the Creative Activities Check Lists are attractive because the focus is on actual performance and the respondent is generally well informed about children's own past achievements. Additionally, Check Lists can be used to assess creative activity in a variety of domains. It is very important to give the current view of creativity as involving domain-specific skills. A large number of investigations have been done on the Creative Activities Check Lists (Cropley, 1972; Hocevar, 1980; Holland, 1961; Runco & Okuda, 1988; Wallach & Wing, 1969). These instruments contain a list of activities which are thought to involve creativity, and the respondent is asked to indicate how many times the student has preformed each. The Check Lists has been used by many studies, and its validity was supported by Runco, Noble, and Luptak (1990).

Problem Finding

The Definitions of Problems and Problem Finding

According to many researchers' studies, definitions of problems and problem finding have emerged very clearly. Problem situations can be distinguished into two types: presented problems and discovered problems (Getzels, 1975). In the former, the problem has a known formulation, a known method of solution, and a known solution. In the latter, the problem does not have a known formulation, a known method of solution. Similarly, Dillon (1982) categorized problems into three types: evident problems, implicit problems, and potential problems. In the first, discrepant events are clearly depicted and subjects do not even have to discover them but rather recognize and identify them. In the second, problems are embedded in the materials and subjects have to sense and formulate problems. In the third, they include assorted objects and there are no problems at all that are neither formulated nor even present. That is, subjects have to construct a problem out of them.

Sternberg (1982) stated that there are two types of problems. One is “well-defined problems”, composed of a clear problem space and well-articulated statements. The other is “ill-defined problems”, composed of an ambiguous problem space and ill-articulated statements. Teachers tend to provide too much information to students, enabling them to gain expertise in solving presented, well-defined problems, but causing them to ignore ill-defined problem situations. Also, Moore (1994) reminded us that students are rarely given the opportunity to pose problems of their own design. As a matter of fact, most problems in the real world are ill-defined. In other words, students cannot transfer problem-solving ability in classroom to problem-solving ability in the real world.

As for the definition of problem finding, many researchers defined problem finding in different ways. Mackworth (1965) stated that problem finding is the detection of the need for a new program based on a choice between existing and expected programs. Mackworth considered problem finding resulted in the discovery of many general questions (discovered problems) from many ill-defined problems situations. Getzels and Csikszentimihalyi (1976) stated that problem finding is the way problems are envisaged, posed, formulated, created. There are some observations to be made about these two definitions. First, problem finding is a new and complex mental and intellectual process. Second, problem finding is the most intricate way in which humans interact with their environment.

According to views of cognitive development, Arlin (1975) identified a different dimension of problem finding. She revealed that problem finding is the fifth stage of adult cognitive development, and may extend beyond the level of formal operations. The problem solving stage is a necessary but not sufficient condition for the problem finding stage. In other words, problem finding may need much higher order thinking than problem solving.

The Measures of Problem Finding and Levels of Problems

Hoover (1992) began to develop a way to measure scientific problem finding ability, and defined scientific problem finding ability as the subjects' abilities to formulate hypotheses in a given realistic situation. According to Hoover's studies, the ability to generate hypotheses is closely related to cognitive styles and attitudes for gifted students. However, the ability to generate hypotheses is independent of intelligence and gender for gifted students. Also, there are significant correlations between a measure of creativity and the ability to formulate hypotheses in gifted fifth-grade students in Hoover's studies.

Jay (1996) gave inquiry session for students to explore floating and sinking task. Floating and sinking materials consisted of three large tubs of water plus numerous items like aluminum, wood blocks, styrofoam pieces, plastic container, iron pot, clay, balloons, candles, pieces of glue, paper clips, erasers, and other items. The subjects were told that they could manipulate and experiment with materials in any way they chose. It was completely up to the subject to decide what to work on. In Jay's studies, problem finding behavior was assessed multiple dimensions: object manipulation, articulation, problem posed, basic activity, types of problems, imaginativeness, richness generation, and distant connections. Jay emphasized on manipulate experiments for finding problems, but in fact students always have thought experiments when they first face problem situation. In thought experiments, students can make extensive use of mental imagery, which implies a high level of cognitive engagement. Also, it is physically autonomous, in that no actual laboratory equipment is involved.

Washton (1967) suggested that how a science teacher treats pupil question very well determine the degree of creativity that may occur in the student. In other words, science teachers recognize and identify certain types of students' questions that may lead to creative behavior. As a result of many classroom observation in junior and senior high schools, a taxonomy of students' questions for creativity was developed: 1. Factual questions: these are low level types of students' questions that can be answered by looking in a textbook or reference book. 2. Questions related to scientific principles or laws: usually these questions can be answered by a statement of s scientific law. 3. Questions related to the ability to transfer or make applications. 4. Spontaneous questions of curiosity. 5. Questions that are genuine problems that need to be solved. Students' questions contribute to varying degrees of opportunities that lead to creativity.

Allison and Shrigley (1986) used more simple criteria to analyze fifth and sixth grade students' questions in science. Students' questions were classified into three categories of operational, non-operational, and responses that could not be classified as questions. Based on Alfke's (1974) model, the definition of operational questions is that ones manipulate variables through elimination, substitution, or increasing or decreasing the presence of the variables. In addition to the quality of questions, Dori and Herscovitz (1999) added a quantitative aspect to use number, orientation, and complexity of problems for evaluating tenth grade students' levels of questions. Attributes of the complexity include application or analysis, interdisciplinary approach, judgment or evaluation, and taking position or personal opinion. They formulated an equation to show the students' aggregate question complexity scores. $C = \sum_{i=1}^{n} (P_i + 1)$: C is the students aggregate question complexity scores, n is the number of questions asked by the students, and P_i $\{0,1,2,3\}$ is the number of attributes which scores a positive value in the complexity category of question i.

Cuccio-Schirripa and Steiner (2000) studied how to enhance and analyze of science question level of middle school students. Middle school students' science question rating scale developed by this study include four levels of questions: 1. memorized statements; 2. descriptions, classifications or comparisons; 3. experiments/ variables must be made specific, measurable, manipulable; 4. experiments/ variables are already specific, measurable, manipulable. The results indicated that students who received instruction on researchable questioning outperformed those students who were not instructed, and high achievers in mathematics, reading, or science outperformed low achievers. Also, students' high-interest question levels are higher than their low-interest question levels, even without instruction. It is suggested here that both instruction and science topics of interest can be used to enhance the development of the students' own researchable questions.

From Creativity to Problem Finding

Problem finding skills are increasingly recognized in theories of creativity, and problem finding has been viewed as the most important component in the creative process (Getzels & Csikszentmihalyi, 1971; Getzels, 1975). Getzels and Csikszentmihalyi conducted the most influential early empirical study of problem finding in art. In their studies, a positive relationship was found between discovery-oriented behavior at problem finding stage and originality and aesthetic of the painting. Furthermore, the publication of The Creative Vision by Getzels and Csikszentmihalyi (1976) created considerable research interest in problem finding and creativity. Wakefield (1991) also claimed that problem finding is a hallmark of creative accomplishment. His creativity model described four combinations of problem finding and problem solving: (1) closed problems/closed solutions; (2) closed problems/open solutions; (3) open problem finding/closed solutions; (4) open problem finding/open solutions. Wakefield indicated that the open problem finding/open solutions situation calls for creative thinking, and it will be true creativity.

The last two decades of publications in problem finding have succeeded in identifying some related factors. For instance, Runco and Okuda (1988) discovered a high correlation among problem finding, divergent thinking and creative performance. In addition, Okuda, Runco, and Berger (1991) argued that real-world problem finding ability might be a meaningful factor in learning science. They found a low correlation between divergent thinking tests and real-world problem finding tasks. Therefore, they suggested that real-world problem finding ability is more predictive of creative performance than standard measurement in divergent thinking.

In fact, the concept of problem finding originated in the science field. Einstein and Infeld (1938, p.83) are repeatedly quoted as saying that "the formulation of a problem is often more essential than its solution." Nevertheless, it never reveals strong reflection in the field of science and teaching. Science emphasizes theories and methodologies, so teachers may only teach how to understand theories and how to solve problems in the science classroom. Thus, teachers and students always ignore the ability of problem finding. However, problem finding is the most important resource in scientific creativity. That is, understanding the importance of problem finding in learning science will help teachers promote students' scientific creativity. The purpose of science education is not to train all students to be scientists, but to teach them how scientists discover problems and concepts. Thus, students are able to apply these learning strategies to their everyday lives.

Many researchers have focused on finding a relationship between problem finding and scientific creativity. Snow (1960) depicted "two worlds" within the scientific community. One is "problem finders" who are better at formulating new concepts, and the other is "problem solvers" who can solve given problems well. In fact, problem finding is more important and complex than problem solving. Moreover, problem finders usually form the greatest contributions and scientific bottlenecks. (Mackworth, 1965) Nowadays, scientific progress is no longer determined by the number of people who are good at solving problems because the best problem solvers are machines. That is, problem finding contributes to meaningful scientific creativity, and then scientific creativity causes scientific progress.

Rostan (1994) tried to find the relationship among problem finding, problem solving, and cognitive controls. In Rostan's study, acclaimed professional producers are the same as problem finders, while postdoctoral research assistants are the same as problem solvers. Rostan found that no significant difference in cognitive abilities between acclaimed professional producers and postdoctoral research assistants of research-oriented universities. According to Rostan's suggestions, opportunities and motivation are probably the main factors which may result in differences between the two groups in problem finding ability, not cognitive ability. Indeed, some students are not good at problem finding; as a result, teachers may attribute these failures to students' intelligence. However, teachers have to take into account the roles of the opportunities and driving forces.

Subotnik's (1994) research also supported Rostan's research, and Subotnik reminded us that curiosity is the most important driving forces. Subotnik explored the ability of problem finding in Westinghouse Science Talent Search winners. All subjects were recognized as science talented, but not all of them generate their own research questions. For many subjects, help came from professionals outside the school and from family. Subotnik and Rostan's research have us think deeply if the ability of problem finding is a very crucial factor for identifying students' creative talent in science domain. There is no denying that opportunities, driving forces, and family or professional support will play major roles in inspiring students' scientific creativity.

Formulating Hypotheses

Hypothesis is defined as an imaginative preconception of what may be true in the form of a declaration with verifiable deductive consequences. Generally speaking, scientific inquiry has two components: hypothesis generation and hypothesis testing (Martin, 1972), but hypothesis testing component usually received adequate emphasis in science classrooms, whereas the hypothesis generation component is not. More recently, the ability to formulate hypotheses is one of the assessment criteria for established National Science Curriculum in England and Wales (Swatton, 1992). The formation of testable hypotheses in central to the development by students of a wide-ranging strategy for pursuing the types of inquiry. Although the ability to propose hypotheses is the same important as the ability to test hypotheses in methodology of science, the vast majority of the work in science education has been done in the context of hypothesis testing, whereas little has been done on the formulation of hypothesis.

Rachelson (1977) described that hypothesis generation consists of mental activities that produce a tentative explanation of a problematic situation. However, the scientists must have numerous hypotheses in mind that may provide explanation for a given problem, but it is extremely important to select the most plausible hypothesis for testing. Furthermore, Rachelson identified five characteristic elements of the hypothesis generation. One of five elements is that hypothesis generation is a diffuse, nonlinear, and imaginary process which is not guided by explicit methodological rules. It reminds us that formulating hypotheses involves creative thinking very much more than collecting data, testing hypotheses, drawing a conclusion, and making inferences in the process of scientific inquiry.

Frederiksen, Evans, and Ward (1975) designed The Formulating Hypotheses (FH) Test to measure abilities of the sort required of a research scholar who is trying to make sense out of research findings and to measure one aspect of scientific creativity. Each item of FH consists of a graph or table showing findings from a research study. The subject is provided with an answer sheet and instructed to write short statements of hypotheses (possible explanation) which you think may account for the finding. Thus, the FH test attempted to simulate an aspect of the creative work of scientists. In FH test, both quality and number of the responses were obtained. Furthermore, Quinn (1971) particularly focused on measurement of quality of hypotheses. Quinn validated the definition of hypotheses through analyzing the philosophy of science literature. Accordingly, she synthesized the following criteria: it makes sense, it is empirically based, it is adequate, it is precise, and it explicitly states a test of its validity. Based on the criteria of the Scale, she used a continuous variable with zero to five ranges, from no explanation, non-scientific explanation, partial scientific explanation, scientific explanation relating at least two variables in general terms, precise scientific explanation with qualification or quantification of the variables, to explicit statement of a test of an hypothesis.

Hoover and Feldhusen (1990) used FH test to explore the scientific hypothesis formulation ability of gifted ninth-grade students. Results indicated that there were no difference between male and female subjects' abilities to formulate hypotheses and the abilities to formulate hypotheses is not highly related to intelligence, aptitude, or noncognitive variables for the gifted students. Finally, a positive relationship was found between the quality and the quantity of subjects' responses. Pouler and Wright (1980) indicated that hypotheses formulation abilities can be taught effectively as part of normal classroom instruction. They suggested that providing students with both of the criteria, acceptance hypotheses and differential reinforcements, leads to an enhanced capacity to produce better hypotheses in new situations.

Nature of Science

Generally, the nature of science refers to the epistemology of science,

science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). Nowadays, understanding the nature of science is a central component of national science education reform efforts. National Research Council (1996) described eight categories of science content standards which outline what students should know, understand, and be able to do in the natural sciences. One of these categories is history and nature of science. In addition to noticing the importance of the nature of science in learning science, we have to recognize that there are some controversies between science educators and philosophers of science on nature of science (NOS) tenets (Alters, 1997), and the nature of scientific knowledge formation differs from scientific discipline to discipline.

However, science educators generally agree that scientific knowledge is tentative and revisionary, and exists the interaction of social and cognitive processes in development of scientific knowledge (Thagard, 1994). Also, Matthews (1994) claimed that although there is not unanimity, there is a reasonable consensus on many lower-level points about NOS. National Academy of Science has been able to produce a series of consensus statements about the NOS in the National Science Education Standards (NRC, 1996). In addition, recommendations about the nature of science contained in eight international science education standards documents show significant overlap (McComas &

Olson, 1998). In other words, although there is a lack of complete agreement regarding what science is and how science works, there is a significant consensus regarding fundamental issues in the nature of science relevant to science education.

NOS traditionally has been treated as declarative knowledge outcomes and measured by objective instruments. Cooley and Klopfer's (1961) Test on Understanding Science (**TOUS**) is widely used and as one of a battery of tests. Some researchers have criticized TOUS strongly. One of the criticisms of TOUS is that some items in TOUS are not related to a student's conception of scientific knowledge and are more relevant to the institution of science and the profession of scientists (Lederman, Wade, & Bell, 1998). Also, Hukens (1963) argued that the TOUS loaded strongly on a verbal factor and the complexity of some items in the TOUS obscured the meaning for tenth grade students. However, Lederman reminded us that TOUS was an excellent beginning for those interested in assessing understandings of the nature of science, even though it appears inappropriate as a sole assessment instrument for understanding of nature of science.

The Nature of Science Scale (**NOSS**) was developed by Kimball (1967-1968) as a tool to determine whether or not science teachers have the same view of science as scientists. Kimball's validation samples included scientists, science teachers, philosophy majors, and science majors. A criticism of the NOSS claimed that its development and validation in a sample of college graduates made it inappropriate for high school populations. The Science Understanding Measure (**SUM**) was developed by Coxhead and Whitefield (1975) and it was based on the TOUS. The specific purpose of SUM is the informative and diagonostic analysis of groups of students in the 11 to 14 age range. The SUM covers five areas: scientists as people, science and society, the role and nature of experiments, theories and models in science, and the unity and interrelatedness of the sciences.

Rubba and Anderson (1978) developed the Nature of Scientific Knowledge Scale (**NSKS**) to assess secondary students' understanding of the nature of scientific knowledge. The NSKS's six subscales are amoral, creative, developmental, parsimonious, testable, and unified. Even though NSKS obtained weak criticism from other researchers, it does possess potentially significant wording problems (Lederman, 1998). For instance, there are some pairs of statements that differ only in that one is stated in the positive and the other in the negative. This redundancy could encourage respondents to check their answers on previous items when they read similarly-worded items later in the questionnaire, and it would affect reliability estimates.

The Views on Science-Technology-Society (**VOSTS**) was developed by Aikenhead and Ryan (1992) and it was a new instrument dealing with STS topics.

The content of VOSTS statements in defined by the domain of science-technology-society content appropriate for high school students and the VOSTS conceptual scheme included science and technology, influence of society on science/technology, influence of science/technology on society, influence of school science on society, Characteristics of scientists, social construction of scientific knowledge, social construction of technology, and nature of scientific knowledge. However, during the past 10 years, interviews and other qualitative methodologies have been more widely used to assess students' knowledge about the nature of science. Some researchers noticed the importance of using qualitative methodologies to determine how students interpret the language of items and how researchers interpret students' written language (Lederman & O'Malley, 1990). Roth and Roychoudhury (1994) also proved that there are indeed discrepancies between students' oral and written responses.

Many researchers focus on assessment of students' conceptions of the nature of science. Students' inadequate understanding of the scientific enterprise and scientists was found (Cooley & Klopfer, 1961; Mackay, 1971). They concluded that students lack sufficient knowledge of the role creativity in science, the function of scientific models, the roles of theories and their relation to research, the relationship between experimentation, models and theories, and absolute truth, and the fact that science is not solely concerned with the collection and classification of facts. Even some studies found that some high school students believed that scientific research reveals incontrovertible and necessary absolute truth.

The problem is that how knowledge about nature of science helps students learn science and why nature of science should be as a goal of science instruction. Driver, et al (1996) answered this question by suggesting five additional arguments supporting the inclusion of the nature of science in science curriculum. These five justification for including the nature of science in science instruction are: understanding the nature of science will help us make sense of the science, manage technological objects and processes they encounter, make sense of socio-scientific issues and participate in decision-making process, appreciate science as a major element of contemporary culture, help us understand norms of scientific community embodying moral commitment, and support successful learning of science content.

However, evidence suggests that knowledge of the nature of science indeed assists students in learning science content, enhances understanding of science, enhances interest in science, enhances decision making, and enhances instructional delivery (McComas, Almazroa, & Clougii, 1998). For instance, Songer and Linn (1991) did find that students with dynamic views of science acquired a more integrated understanding of thermodynamics than those with static views. The dynamic view of science means that scientific knowledge is tentative, whereas the static view means that science is a group of facts that are best memorized. Also, some researchers suggested that NOS courses should be involved in science teacher education programs (Mattews, 1994; Wandersee, 1986). The main idea they provided is that understanding the nature of science is likely to enhance teachers' ability to implement conceptual change models of instruction. In other words, understanding the process of historical conceptual development in science may enhance individual cognitive development. Thus, teachers' interest in NOS will help themselves understand the psychology of students' learning.

Attitudes toward Science

Many researchers may define attitudes toward science in a variety of ways. Haladyna and Shaughnessy (1982) offered the definition of attitudes toward science by using meta-analysis. Attitudes toward science address scientific attitudes, attitudes toward scientists, attitudes toward scientific careers, attitudes toward methods of teaching science, scientific interests, attitudes toward parts of the curriculum, or attitudes toward the subject of science. The instrument, Science Attitude Inventory (SAI), developed by Moore and Sutman (1970) is probably best known and most widely used as measure of scientific attitudes. After 25 years, Moore and Foy (1997) developed new version, SAI II, to improve validity of SAI. Moore eliminated gender-biased references, eliminated words that have been criticized as difficult for readers to understand, and shortened the instrument to make it easier to use. In SAI II, six position statements assess different dimensions of students' attitudes toward science. The first position statement is to assess students' attitudes toward scientific knowledge itself and the process of discovering science knowledge. The second is to assess students' attitudes toward the concept of the almighty of science and scientists. The third is to assess students' attitudes toward scientific methodology. The fourth is to assess students' attitudes toward purposes and functions of science. The fifth is to assess students' attitudes toward science liberal education. The sixth is to assess students' attitudes toward science interests and science careers.

Commonsense might suggest that attitudes and cognitive variables such as intelligence and achievement must to be strongly related. In fact, the available evidence points to the relationship being relatively weak. Clarke (1972) found that no differences between high IQ and low IQ children in their attitudes to science. Wynn and Bledsoe (1967) found no relationships between achievement and attitudes to science. In some studies, there is even a negative relationship was found: the more able students were less interested in science, and students with higher grades had negative attitudes toward science (Baker, 1985; Richardson & Stanhope, 1971).

Even though there are unclear relationships between attitudes and cognitive variables, there is no doubt that attitudes toward science, especially in interest toward science, must be a considerable factor in affecting the performance of scientific creativity. Numerous of researchers suggested a strong connection between interest and creativity, so scientific interest should be obtained much more attention in exploring the relationship between students' scientific creativity and attitudes toward science. Duke (1972) argued that there is no clear correlation between personality type and creativity, intelligence and creativity, experience and creativity, knowledge and creativity, but there is most important relationship among interest, confidence and creativity. Duke indicated that lack of creativity is characterized mainly by an incapacity or disinclination to become interested, and interest and confidence are closely interrelated. In other words, once someone has the strong degree of interest and confidence, he will work hard in accumulating the particular knowledge associated with his interest.

Many psychological theorists suggested that creativity will be most likely result from an intrinsically motivated state. Hennessey and Amabile (1988) found that there exists a strong and positive link between a person's motivational state and creativity of the person's performance. They used the term 'intrinsic motivation principle of creativity" that means "people will be most creative when they feel motivated primarily by the interest, enjoyment, satisfaction, and challenge of the work itself – not by external pressures". Also, they reminded us that a more positive approach to maintain creativity is to maintain intrinsic motivation.

In addition to intrinsic motivation, Vernon (1987) claimed that successful scientists are more often firstborn or only children than in the general population. It was not because any genetic advantage but rather to the higher aspirations of parents for their eldest children. Bloom and Sosniak (1981) studied the development of outstanding talent among 25 men and showed the great amount of support and planning given by the home form age 12 or even earlier. More time was commonly spent on coaching, learning, and practice than on schoolwork. However, these conclusions probably apply more to the athletically and artistically talented than to future scientists. Also, having a future career image and definite role models, mentors, and paragons are important factors influencing the development of creators in many fields (Tardif & Sternberg, 1988). Simpson and Troost (1982) reminded that family interest, family's support of science, and friends' effect also play considerate roles in influences on students' commitment to science, in addition to science self-concept, achievement motivation, science anxiety, environment and climate in science class, science teacher, and science curriculum.

Summary

There is tension between domain-general and domain-specific theories in creativity research. However, there is no doubt that knowledge is a considerable factor in scientific creativity performance. Scientific creativity usually involves some addition to our prior knowledge, whereas artistic creation may give some new representation of life or feelings, but not usually give a progress from previous representations.

Problem finding is increasingly recognized in theories of creativity, and problem finding has been viewed as the most important component in the creative process. Some researchers claimed that scientific creativity is the ability to find new problems; some researchers treated the ability of problem finding as the ability of formulating hypotheses. However, some evidence showed opposite findings: one is that some students recognized as science talented even did not generate their own research questions; the other is that there is no correlation between the ability of problem finding and the ability of formulating hypotheses. The interwoven relationships among the ability of problem finding, the ability of formulating hypotheses, and scientific creativity may shed some light on exploring students' science learning.

Nowadays, understanding the nature of science is a central component of national science education reform efforts. Evidence suggested that knowledge of the nature of science indeed assists students in learning science content, enhances understanding of science, enhances interest in science, enhances decision making, and enhances instructional delivery. However, there are no studies to explore the relationship between the nature of science and scientific creativity even for scientists. It may be a meaningful issue to know better what kind of role the nature of science plays in the process of scientific creativity. Additionally, numerous researchers suggested a strong connection between interest and creativity, so scientific interest should be received much more attention in exploring the relationship between students' scientific creativity and attitudes toward science. Moreover, a future career image, definite role models, mentors, paragons, opportunities, driving forces, and family or professional support are important factors influencing the development of creators in many fields.

CHAPTER 3

METHODOLOGY

This chapter presents the research methods and procedures of this study, including sections of research design, participants, instrumentation, data collection, and data analysis.

Research Design

The purpose of this study is to explore the correlation between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Correlations among scientific creativity and these variables may help understand the nature of students' scientific creativity and determine significant predictors of eleventh-grade students' scientific creativity in the process of learning science. The first step of this study was to investigate the correlations among scientific creativity and these selected variables. This research design is especially useful for exploratory studies in areas where little is known. Students' scientific creativity has received minimal attention, and few researchers have focused on finding effective predictors for students' scientific creativity. From a review of previous research and theories covered in Chapter Two, variables such as creativity (fluency, resistance to closure, flexibility, originality, elaboration, and abstractness), problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science were identified in this study.

Moreover, a prediction study was conducted. Educational researchers have conducted many prediction studies, usually with the aim at identifying variables that forecast some behavior success. Prediction studies are similar to correlation studies in that both involve computing correlations between a complex behavior patterns (a criterion such as scientific creativity in this study) and variables (13 variables in this study) thought to be related to the criterion. Also, prediction studies tend to be more concerned with maximizing the correlation between the predictor variables and the criterion, whereas correlation studies seek to describe if the extent of a correlation is high, moderate, or low. Some better predictors that have higher correlation with scientific creativity were obtained from 13 selected variables in previous analysis of Pearson product-moment correlation in the correlation study. The multiple correlation coefficient was obtained in this prediction study. Through a serious of stepwise multiple regressions, the most significant predictors were obtained for predicting students' scientific creativity.

Participants

The subjects chosen to participate in this study were N = 130 male eleventh-grade students. Due to some participants' missing items on the questionnaires, 13 cases were discarded from the original data set, resulting in the final total sample of N = 117 cases. These students enrolled in three biology classes were taught by the same biology teacher at an urban public senior high school located in northern Taiwan during the Spring semester, 2002. The biology course is required for every eleventh-grade student in senior high schools in Taiwan.

There were three reasons why these students were chosen as participants in this study. First, this urban public senior high school is a typical school in Taipei, the largest city in Taiwan. The academic abilities of students in every class are normally distributed because of no tracking policy in the school. Second, these students in the three different classes were taught by the same biology teacher; therefore teacher effects were properly controlled. Third, on a personal level, the researcher is familiar with this senior high school and the biology teacher, who used to be the researcher's classmate in graduate school. This familiarity proved to be very helpful in carrying out this study.

Instrumentation

The *Test of Divergent Thinking* designed by Williams (1980) was used to measure creativity. Two instruments (*Creativity Rating Scale* and *Creative Activities and Accomplishments Check Lists*) were used to measure scientific creativity from different perspectives in this study. The *Creativity Rating Scale* developed by Renzulli (1983) was modified by the researcher for this study. The *Creative Activities and Accomplishments Check Lists* developed by Runco (1987) was modified by the researcher for this study. In addition, the *Nature of Scientific Knowledge Scale* was designed to measure students' understanding of the nature of science. It was developed by Rubba and Anderson (1978) and modified by the researcher for this study. The *Science Attitude Inventory II* was designed by Moore and Foy (1997) to measure students' attitudes toward science. Finally, two instruments for measuring students' abilities of problem finding and abilities of formulating hypotheses were developed by the researcher in this study. These instruments are as follows:

1. For creativity measurement, the *Test of Divergent Thinking (TDT)* was used.
2. For measurement of scientific creativity,
    a. The *Creativity Rating Scale (CRS)* was used (see Appendix B).

b. The *Creative Activities and Accomplishments Check Lists (CAACL)* was used (see Appendix C).

3. For measurement of the nature of science, the *Nature of Scientific Knowledge Scale (NSKS)* was used (see Appendix D).
4. For measurement of attitudes toward science, the *Science Attitude Inventory II (SAI II)* was used (see Appendix E).
5. For measurement of problem finding, the *Problem Finding (PF)* was used (see Appendix F).
6. For measurement of formulating hypotheses, the *Formulating Hypotheses (FH)* was used (see Appendix G).

Open-ended questions were added to the end of the *SAI II* to elicit additional information on students' motivation and interest toward science learning as well as their learning backgrounds. All instruments were translated by the researcher from English into Chinese. (see Appendices H, I, J, K, L, and M). A high school teacher with a specialization in biology and science education reviewed the translated instruments to validate the accuracy and clarity of the Chinese translation. Another Taiwanese doctoral student with a specialization in foreign language and professional translation verified the translated instruments through back-translation to ensure their accuracy.

The *Test of Divergent Thinking (TDT)*

The *Test of Divergent Thinking* developed by Williams (1980), is a popular creativity test battery which also contains complete scoring guides, norms, and validity. The *Test of Divergent Thinking* is used to assess the components of creativity in terms of fluency, flexibility, originality, elaboration, and semantic transformation. The *Test of Divergent Thinking* based on the early version of the *Torrance Tests of Divergent Thinking* includes 12 figural items, all of which require a test taker to create a meaningful drawing from an incomplete or abstract form. Lin (1994) used hundreds of students in Taiwan field testing to validate and modify the *Test of Divergent Thinking*. Lin recommended the use of a streamlined scoring system for the figural tests. The streamlined scoring evaluates six norm-referenced measures: fluency, resistance to closure, flexibility, originality, elaboration, and abstractness of titles.

The interscorer reliability coefficients of the *Test of Divergent Thinking* ranged from 0.88 to 0.99; the test-retest reliability coefficients ranged from 0.50 to 0.81 ($p < 0.05$); and the Cronbach alpha reliability coefficients ranged from 0.56 to 0.81. Generally speaking, the use of the scoring guidelines of the *Test of Divergent Thinking* for students in Taiwan is reliable. In this present study, students' scores on the *Test of Divergent Thinking* were analyzed by using the norms and scoring guidelines developed in Taiwan, therefore, the effects of cultural bias may have been eliminated or minimized.

Scientific Creativity (SC)

The total scores of students' scientific creativity were composed of two independent scores from two instruments: the *Creativity Rating Scale*, and the *Creative Activities and Accomplishments Check Lists*.

1. The *Creativity Rating Scale (CRS)* (see Appendix B)

Renzulli's ten-item creativity rating scale, part of Scales for ratings the Behavior Characteristics of Superior Students, is used by teachers to rate the creativeness of students of any age (Renzulli, 1983). There are four scoring weights: 0 = seldom or never, 1 = occasionally, 2 = considerably, and 3 = almost always. The coefficient of stability is 0.79, and the interjudge reliability is 0.91. There are about 45 students in each classroom in the high school in Taiwan. Because of the size of the class, teachers are usually not able to be familiar with each student. Therefore, it may not be appropriate for teachers to use this rating scale in Taiwan. In this study, Renzulli's ten-item creativity rating scale was used for peer ratings, and it was conducted in groups. For example, there were four students in the same group in biology or chemistry experiment class. Each student rated the other three members and himself/herself in the same group. Each student obtained four scores from their group members and himself/herself. Finally, each student obtained a final score which is an average of the four scores.

Renzulli's ten-item creativity rating scale was modified in this study. The main difference is the change in general situations to scientific situations. For example, item number 1: "Displays a great deal of curiosity about many things; is constantly asking questions about anything and everything" was changed to "Displays a great deal of curiosity about many things in science learning; is constantly asking questions about anything and everything in learning science".

2. The *Creative Activities and Accomplishments Check Lists (CAACL)*

(see Appendix C)

The *Creative Activities and Accomplishments Check Lists* are used to assess the creative performance of children. It is the most popular approach for assessing students' creativity in a specific domain. The *Creative Activities Check Lists* (Hocevar, 1980; Runco, 1987, 1993) used 52 creative activities in four domains: writing, crafts, science, and art. The *Creative Activities Check Lists* contain a list of activities that involve creativity and the respondent is asked to indicate how many times children has performed each.

The *Creative Activities Check Lists* has been used in many studies. Its validity was supported by Runco, Noble, and Luptak (1990). In Runco's studies, the Cronbach alpha reliability coefficient is 0.91 in the science domain, 0.81 in art, 0.71 in crafts, and 0.77 in writings. Creative activities only in the science domain were chosen for use in this study, so each student has a total score in the science domain of The *Creative Activities and Accomplishments Check Lists*.

In this present study, the correlation between the score of *Creativity Rating Scale* and the score of the *Creative Activities and Accomplishments Check Lists* was 0.71 ($p < 0.01$). The *Creativity Rating Scale* was designed to assess students' personal characteristics in creativity, and the *Creative Activities and Accomplishments Check Lists* were designed to assess creative products of students. Personal characteristics and students' creative products were two classifications in two different dimensions (X axis and Y axis, see Figure 3). The students' scientific creativity were assumed to be composed of these two classifications, so the total score for scientific creativity was the area of multiplying the creative products by the personal characteristics (see Appendix N). The area of scientific creativity is represented by the shaded portion of Figure 3.

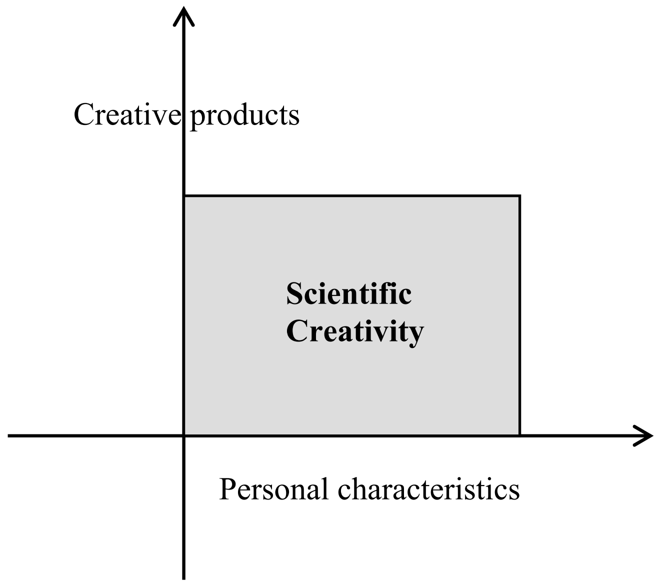

Figure 3. Scientific creativity: the area of multiplying the creative products by the personal characteristics

The *Nature of Scientific Knowledge Scale (NSKS)* (see Appendix D)

Rubba and Anderson (1978) developed the *Nature of Scientific Knowledge Scale* (***NSKS***) to assess secondary students' understanding of the nature of scientific knowledge. A total of 48 statements are included in a Likert-scale format. The NSKS's six subscales are amoral, creative, developmental, parsimonious, testable, and unified. For reliability, NSKS's overall Cronbach alpha reliability coefficient is 0.74 for biology and chemistry students (grade 9, 10 and 11), and Cronbach alpha reliability coefficient is 0.89 for advanced chemistry students (grade 12). For validity, content validity was judged by a panel of experts. The construct validity was examined after its development by testing an anticipated difference in understanding of the nature of science between two groups of college freshman: freshman completing a philosophy of science course and freshman without formal philosophy of science background completing a biology course for non-science majors. These findings were evidence of NSKS validity.

However, NSKS possesses potentially wording problems (Lederman, 1998). For instance, there are some pairs of statements that differ only in that one is stated in the positive and the other in the negative. For example, "scientific knowledge expresses the creativity of scientists" and "scientific knowledge does not express the creativity of scientists." It could encourage students to check their answers on previous items when they read similarly-worded items later in the questionnaire. Thus, some redundancy statements were discarded or modified in this study. For example, "scientific knowledge does not express the creativity of scientists" was changed to "discovering new scientific laws, theories, and concepts does not require creative thought." The modified *Nature of Scientific Knowledge Scale* was used to measure the nature of science in this study. A total of 36 statements were presented in a Likert-scale response format containing five choices: strongly agree, agree, neutral, disagree, and strongly disagree. In this study, modified NSKS's overall Cronbach alpha reliability coefficient is 0.75 for 117 senior high school students (grade 11).

The *Science Attitude Inventory II (SAI II)* (see Appendix E)

Scientific Attitude Inventory (*SAI*) was developed by Moore and Sutman (1970) and it has been used extensively throughout the world. After 25 years, Moore and Foy (1997) developed a new version, *SAI II*, to improve the validity of *SAI*. Moore eliminated gender-biased references, revised words that have been criticized as difficult for readers to understand, and shortened the instrument to make it easier to use. The 40 item, Likert-type *SAI II* was field tested with hundreds of students in grades 6, 9, and 12. Its split-half reliability coefficient is 0.805, and Cronbach's alpha reliability coefficient is 0.781 reported by Moore. With respect to validity, the results of an administration of the *SAI II* to 588 students, indicated that the scale of the instrument distinguished between those who have more positive attitudes toward and those who have less positive attitudes toward science as determined by the total score of the *SAI II*. In this study, *SAI II*'s overall Cronbach alpha reliability coefficient is 0.78 for 117 senior high school students (grade 11).

Open-ended questions such as family support, career images, readings about science, role models, parents' expectations, and preferences for science were added to the end of *SAI II*. For example, the first question is “Does your family encourage you to learn science? How do they encourage you?” The last question is “Do you like biology? How do you like biology?” Open-ended items elicit additional information on students’ motivation and interest toward science learning. For example, we can understand better if students with higher scientific creativity had more support from family or read more scientific journals and books outside class. Open-ended questions offered additional information about the learning backgrounds of students.

Problem Finding (PF) (see Appendix F)

For measuring students’ abilities related to problem finding, the *Problem Finding Instrument* was developed by the researcher for this study. The *Problem Finding Instrument* is an open-ended type instrument. Questions in the instrument are open-ended to encourage students to express their ideas thoroughly. Students were given two ill-defined problem situations related to biology and then they had to find the problems they wanted to explore in these two scientific problem situations. Every student obtained a total score composed of two independent subscores: levels of problems and degrees of rareness of problems. Levels of problems were scored in terms of middle school students’ science question rating scale (Cuccio-Schirripa & Steiner, 2000). Middle school students’ science question rating scale consists of three levels as follows: level 1: memorized statements; level 2: descriptions/classifications/ comparisons; level 3: experiments with dependent and independent variables. Based on the level of this scale, a continuous variable with one to three ranges from level 1 to level 3 was used for scoring. Level 1 was represented by 1 point; level 2 was represented by 2 points; and level 3 was represented by 3 points. Levels of problems were scored by two science teachers.

With regard to degrees of rareness of problems, the frequencies of every problem mentioned by students were carefully counted. If a problem was mentioned by two students, it would be ranked level A (frequency: 0-5). If a problem was mentioned by seven students, it would be ranked level B (frequency: 6-10). Level A (frequency: 0-5) was represented by 9 points; level B (frequency: 6-10) was represented by 8 points; level C (frequency: 11-15) was represented by 7 points; level D (frequency: 16-20) was represented by 6 points; level E (frequency: 21-25) was represented by 5 points; level F (frequency: 26-30) was represented by 4 points; level G (frequency: 31-35) was represented by 3 points; level H (frequency: 36-40) was represented by 2 points; and level I (frequency: 41-45) was represented by 1 point. Thus, every student had a total score in degrees of rareness of problems. Interrater reliability was computed as 0.95 and few disagreements were resolved by discussions between the raters after completing the scoring procedure.

After obtaining two different scores of levels of problems and degrees of rareness of problems, both scores were calculated into cumulative percentiles. Thus, the total score of every student was represented by the average of these two cumulative percentiles (see Appendix N).

Formulating Hypotheses (FH) (see Appendix G)

For measuring students' abilities of formulating hypotheses, the *Formulating Hypotheses Instrument* was developed for this study. The *Formulating Hypotheses Instrument* is an open-ended type instrument. Questions in the instrument are open-ended to encourage students to express their ideas thoroughly. Students were given two problems related to biology, and then they had to formulate all possible hypotheses in these two scientific problems. Every student obtained a total score composed of two independent subscores: levels of hypotheses, and degrees of rareness of hypotheses. Levels of hypotheses were scored in terms of Quinn's (1971) measurement of quality of hypotheses. Quinn validated the definition of hypotheses through analyzing the philosophy of science literature. According to Quinn's criteria, three levels were used in this study in the following terms: level 1: non-scientific explanation; level 2: partial scientific explanation, incomplete reference to variables; level 3: scientific explanation relating at least two variables. Based on the level of this scale, a continuous variable with one to three ranges from level 1 to level 3 was used for scoring. Level 1 was represented by 1 point; level 2 was represented by 2 points; and level 3 was represented by 3 points. Levels of hypotheses were scored by two science teachers.

With regard to degrees of rareness of hypotheses, frequencies in every hypothesis mentioned by students were calculated. If a hypothesis is mentioned by two students, it will be ranked level A (frequency: 0-5). If a hypothesis was mentioned by seven students, it will be ranked level B (frequency: 6-10). Level A (frequency: 0-5) was represented by 9 points; level B (frequency: 6-10) was represented by 8 points; level C (frequency: 11-15) was represented by 7 points; level D (frequency: 16-20) was represented by 6 points; level E (frequency: 21-25) was represented by 5 points; level F (frequency: 26-30) was represented by 4 points; level G (frequency: 31-35) was represented by 3 points; level H (frequency: 36-40) was represented by 2 points; and level I (frequency: 41-45) was represented by 1 point. Thus, every student had a total score in degrees of rareness of problems. Interrater reliability was computed as 0.94 and few disagreements were resolved by discussions between the raters after completing the scoring procedure.

After obtaining two scores in levels of hypotheses and degrees of rareness of hypotheses, both scores were calculated into cumulative percentiles. Thus, the total score of every student was represented by the average of these two cumulative percentiles. (see Appendix N).

Data Collection

In this study, N = 130 students in three biology classes taught by the same biology teacher were chosen. The researcher went to each classroom at a pre-arranged time during their regular biology class to administer the assessments in person. Using Chinese, the researcher informed the participants of the purpose of the survey and provided instructions about how to answer the assessments. The students were guaranteed that all the data they provided would be kept strictly confidential, so that their teachers would not have access to the personal data. The researcher told them what they needed to do was to give honest responses based on their real learning situations.

A consent form (see Appendix A) was signed and collected before the administration of the assessments. The students were asked to answer all assessments, including the TDT, the CRS, the CAACL, the NSKS, the SAI II, the PF, and the FH in the classroom. After the students had completed the assessments, their answers were collected by the researcher. The data of 13 cases that failed to answer all necessary questions or answered in an inconsistent manner were discarded prior to further analysis. The final valid cases consisted of N = 117 participants. In addition, the students' science achievement (physics, chemistry, and biology) in this semester were collected after obtaining permission of the principal of the school. In Taiwan, science achievement is the sum of a series of diagnostic and summative science content tests at school.

Data Analysis

Statistical Analyses

The quantitative analysis in this study was conducted by using the SPSS (Statistics Package for the Social Sciences) version 10.1 through the following statistical methods:

1. Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participants' responses to all assessments. The scores of the negatively worded items in the *NSKS* and the *SAI II* had first been reversed so that all items had the same response scale value.
2. Pearson product-moment correlation was used to determine the degree that quantitative variables were linearly related. The correlations among scientific creativity and selected variables were conducted. An

intercorrelation matrix for all variables was collected in this study. These correlational analyses can help address the first research question: "Are there significant correlations among scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, attitudes toward science in the process of learning science by eleventh-grade students?"

3. Stepwise multiple regression was performed to indicate the most significant predictors of scientific creativity. Stepwise multiple regression can help address the second research question: "What are significant predictors of scientific creativity in the process of learning science by eleventh-grade students?" In the first step, the best predictor which has highest correlation with scientific creativity was obtained from selected variables in a previous analysis of Pearson product-moment correlation. The variable selected in the second step is the variable that has the highest correlation with scientific creativity when the previously entered independent variable is partialed out. Each successive step progresses in a like manner: The next predictor variable is entered into the regression equation that has the greatest partial correlation with the criterion when all variables already included in the previous regression equation have been

partialed out. Finally, the most appropriate predictors were obtained for predicting scientific creativity.

Analysis of the Open-ended Questions

The goal of open-ended questions is to elicit additional information on students' motivation, interest and background in science learning. Some information of family support, career images, readings about science, role models and parents' expectations was obtained from the first four open-ended questions in the end of SAI II (Appendix E). The responses to these four open-ended questions from the participants were complied and organized. The responses of the top 10% students (rankings in scientific creativity) were compared with those of the lowest 10% students in open-ended question responses. The results of the comparison among these students in open-ended questions can help address the third research question: "Are students with a higher degree of scientific creativity different from those students with a lower degree of scientific creativity on variables such as family support, career images, readings about science, role models, and parents' expectations?"

In addition, the last three questions related to students' preferences for physics, chemistry, and biology were transformed into a quantitative form. Based on students' responses, five levels were used in this study as follows: level 1:

strongly dislike; level 2: dislike; level 3: neutral; level 4: like; and level 5: strongly like. Level 1 was represented by 1 point, and level 5 was represented by 5 points. Next, the relationships among students' preferences for science and science achievement were conducted by using a Pearson product-moment correlation.

Summary

The purpose of this study is to explore the correlation between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Correlations among scientific creativity and these variables may help understand the nature of students' scientific creativity and determine significant predictors of eleventh-grade students' scientific creativity in the process of learning science. The main assessments including the *TDT*, the *CRS*, the *CAACL*, the *PF*, the *FH*, the *NSKS*, and the *SAI II* were conducted. Descriptive statistics were utilized to describe the participants' responses to all assessments. An analysis of correlations was conducted to determine the correlations between scientific creativity and selected variables. An analysis of stepwise multiple regression was used to indicate the most significant predictors of scientific creativity. With respect to open-ended questions, a comparison between students with a higher and a lower degree of scientific creativity was performed for identifying some other variables such as family support, career images, readings about science, role models, and parents’ expectations. The correlations among students’ preferences for science and science achievement were also conducted.

CHAPTER 4

RESULTS

The purpose of this study was to explore the correlation between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Correlations among scientific creativity and these variables may help understand the nature of students' scientific creativity and determine significant predictors of eleventh-grade students' scientific creativity in the process of learning science. Three research questions guided this study are presented as follows:

1. Are there significant correlations among scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, attitudes toward science in the process of learning science by eleventh-grade students?
2. What are significant predictors of scientific creativity in the process of learning science by eleventh-grade students?
3. Are students with a higher degree of scientific creativity different from those students with a lower degree of scientific creativity on variables such as family support, career images, readings about science, role models, and parents' expectations?

This chapter presents the results of the study in four main sections: (1) results of correlations between variables, (2) results of stepwise multiple regression, (3) results of open-ended questions on students' family support, career images, readings about science, role models, parents' expectations and preferences for science, (4) findings on the NSKS and SAI II.

Results of Correlations between Variables

Table 2 presents the means and standard deviations as well as the actual range of scores for all variables in this study. The total scores for scientific creativity were composed of two independent scores from two instruments: the *Creativity Rating Scale*, and the *Creative Activities and Accomplishments Check Lists*. The total scores of problem finding were composed of two independent subscores: levels of problems, and degrees of rareness of problems. The total scores of formulating hypotheses were composed of two independent subscores: levels of hypotheses, and degrees of rareness of hypotheses. Additionally, creativity was represented by six different dimensions: fluency, resistance to closure, flexibility, originality, elaboration, and abstractness. The range of scores on each variable was fairly wide.

Correlation coefficients were computed among the 13 selected variables. The results of the correlational analyses presented in Table 3 show that 7 out of

Table 2. Means, standard deviations, and range of scores for variables

Variables	M	SD	Range
Scientific Creativity			
Creativity Rating Scale	11.46	5.71	1-28
Creative Activities Check Lists	9.91	5.21	1-27
1. Nature of Science (NSKS)	134.80	8.07	116-169
2. Attitudes toward Science (SAI II)	141.13	10.29	114-166
3. Problem Finding			
Levels of problems	10.56	4.34	3-20
Degrees of rareness of problems	12.35	5.65	3-31
4. Formulating Hypotheses			
Levels of hypotheses	12.58	4.69	4-22
Degrees of rareness of hypotheses	13.42	6.87	4-30
5. Fluency	10.92	2.19	6-12
6. Resistance to Closure	20.03	4.44	4-30
7. Flexibility	6.58	1.76	2-10
8. Originality	13.88	4.16	3-24
9. Elaboration	11.78	3.86	4-28
10. Abstractness	14.11	4.49	5-28
11. Physics Achievement	45.44	13.06	24-83
12. Chemistry Achievement	58.92	14.47	30-89
13. Biology Achievement	70.22	11.24	49-92

Note: N = 117

the 13 predictors of scientific creativity were significantly associated with the criterion variable (scientific creativity). These seven predictors were nature of science, attitudes toward science, problem finding, formulating hypotheses, resistance to closure, originality, and elaboration, and they were significant at $p < 0.01$. Attitudes toward science and problem finding significantly correlated with scientific creativity (0.591 and 0.449, respectively, $p < 0.01$). Nature of science, formulating hypotheses, resistance to closure, originality, and elaboration all significantly correlated with scientific creativity (0.245, 0.28, 0.304, 0.256 and 0.282, respectively, $p < 0.01$). However, the results indicated the lack of significant correlations between scientific creativity and fluency, flexibility, abstractness, and science achievement.

Attitudes toward science play a major role in affecting students' scientific creativity in this study. The more positive attitudes toward science students had, the higher scientific creativity students possibly performed. The ability of problem finding is another important index of students' scientific creativity in this study. With regard to the correlation between creativity and scientific creativity, there are just three subscales including resistance to closure, originality, and elaboration correlated with scientific creativity among six subscales of creativity (fluency, resistance to closure, flexibility, originality, elaboration, and

Table 3. Intercorrelation matrix for all variables

	SC	NOS	ATS	PF	FH	C1	C2	C3	C4	C5	C6	PHY	CH	BIO
NOS	0.245**	–												
ATS	0.591**	0.374**	–											
PF	0.449**	0.200*	0.265**	–										
FH	0.280**	0.092	0.144	0.448**	–									
C1	0.062	0.020	0.077	0.088	0.175	–								
C2	0.304**	0.127	0.09	0.387**	0.317**	0.604**	–							
C3	0.177	0.064	0.143	0.200*	0.264**	0.765**	0.485**	–						
C4	0.256**	0.043	0.037	0.102	0.143	0.654**	0.609**	0.493**	–					
C5	0.282**	0.096	0.093	0.379**	0.313**	0.637**	0.801**	0.481**	0.613**	–				
C6	0.163	-0.093	0.133	0.125	0.146	0.587**	0.522**	0.422**	0.416**	0.554**	–			
PHY	0.124	0.006	0.188*	0.170	0.065	-0.030	-0.029	-0.088	-0.008	-0.018	0.055	–		
CH	-0.007	-0.003	0.113	0.106	0.016	0.006	0.048	0.043	0.092	0.052	-0.001	0.476**	–	
BIO	0.032	0.049	0.098	0.163	0.170	0.007	0.182*	0.082	0.089	0.162	0.063	0.210*	0.259**	–

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

SC: scientific creativity, NOS: nature of science, ATS: attitudes toward science, PF: problem finding, FH: formulating hypotheses, C1: fluency, C2: resistance to closure, C3: flexibility, C4: originality, C5: elaborate, C6: abstractness

abstractness). Science achievement in physics, chemistry, and biology respectively showed no correlations with students' scientific creativity.

In terms of correlations among all selected variables, a significant correlation existed between problem finding and formulating hypotheses (0.448, $p < 0.01$) and significant correlations between problem finding and resistance to closure and elaboration (0.387 and 0.379, respectively, $p < 0.01$). In addition, there was a significant correlation between attitudes toward science and nature of science (0.374, $p < 0.01$). No significant correlations between attitudes toward science and science achievement in physics, chemistry, and biology were evident. All six subscales of creativity (fluency, resistance to closure, flexibility, originality, elaboration, and abstractness) significantly correlated with each other (0.416 − 0.801, $p < 0.01$). The highest correlation between resistance to closure and elaboration was found (0.801, $p < 0.01$). As for science achievement, there were significant correlations between chemistry achievement and physics, and biology achievement (0.476 and 0.259, respectively, $p < 0.01$). A low correlation between physics achievement and biology achievement (0.210, $p < 0.05$) was evident.

The ability of problem finding seems to bond to the ability of formulating hypotheses to some extent (0.448, $p < 0.01$). With regard to the correlation between problem finding and creativity, two subscales of creativity including resistance to closure and elaboration correlated with problem finding. The correlations among six subscales of creativity were interwoven, indicating that the six different dimensions of creativity are not independent. The highest correlation between resistance to closure and elaboration showed that it probably exists the similar nature between these two subscales. Additionally, there were no correlations between science achievement and all other variables, while there were only significant correlations among science achievement themselves in physics, chemistry, and biology.

Results of Stepwise Multiple Regression

A stepwise multiple regression analysis was conducted to predict the scientific creativity from selected variables. The predictors were the 13 selected variables, while the criterion variable was scientific creativity. Table 4 shows that four variables (attitudes toward science, problem finding, resistance to closure, and originality) representing three of the four categories of decision-making influences were entered into the equation ($F = 25.975$, $p = 0.000$).

The multiple correlation coefficient was 0.694, indicating that approximately 48% ($R^2 = 0.481$) of the variance of the scientific creativity can be accounted for by the linear combination of the four variables including attitudes toward science, problem finding, resistance to closure, and originality. In terms of contributions of the individual predictors, the attitudes toward science alone accounted for approximately 35% of the variance of scientific creativity, and the problem finding accounted for approximately 9% of the variance of the scientific creativity. The other variables (resistance to closure and originality) contributed an additional 4% (48% - 35% - 9% = 4%) of the variance of the scientific creativity.

Table 4. Stepwise multiple regression of independent variables on scientific creativity

Predictor Variables	R	R^2	Adjusted R^2	R^2 Change	F	Sig.
1. ATS	0.591	0.349	0.343	0.349	61.626	0.000
2. PF	0.664	0.441	0.431	0.092	44.969	0.000
3. RTC	0.680	0.463	0.449	0.022	32.465	0.000
4. ORI	0.694	0.481	0.463	0.018	25.975	0.000

ATS: attitudes toward science, PF: problem finding,
RTC: resistance to closure, ORI: originality

From a series of multiple regressions, only four significant predictors including attitudes toward science, problem finding, resistance to closure, and originality accounted for 48% of the variance of the scientific creativity, even though there were seven variables significantly correlated with scientific creativity. Attitudes toward science and problem finding were undoubtedly the first two best predictors since both of them have comparatively higher correlations with scientific creativity. Due to collinearity, nature of science and formulating hypotheses did not improve on the prediction made by the first two predictors so that they did not enter the multiple regression analysis.

With respect to six subscales of creativity, resistance to closure and originality were another two significant predictors of students' scientific creativity, even though the correlation between elaboration and scientific creativity was higher than the correlation between originality and scientific creativity. Therefore, a high collinearity existed between resistance to closure and elaboration ($r = 0.801$), so elaboration did not enter the multiple regression analysis as a predictor.

Results of the Open-ended Questions

Family Support, Career Images, Readings about Science, Role Models, and Parents' Expectations

The responses of the top 10% students (rankings in scientific creativity) were compared with those of the lowest 10% students in open-ended questions. The top 10% students in the performance of scientific creativity were defined as students with a higher degree of scientific creativity. The lowest 10% students in the performance of scientific creativity were defined as students with a lower degree of scientific creativity. A total of students in the top 10% were 12, and a total of students in the lowest 10% were 12. From the results of open-ended questions, students with a higher degree of scientific creativity reported much family support and encouragement in learning science. As shown in Table 5, many students reported that their parents subscribed to science magazines for them, bought science equipment for them, encouraged them to attend scientific contests and summer science programs, encouraged them to read scientific readings outside of school, and others. These students also reported that they enjoyed reading science magazines and books related to science such as Newton, Little Newton, Scientists, and Copernicus, and to watch TV programs such as Discovery, and The Earth. These magazines and TV programs are very popular public access to general science in Taiwan.

Most students with a higher degree of scientific creativity reported that they would choose careers related to science and technology in the future. For instance, these careers they mentioned were biochemist, geologist, doctor, scientist, mechanic engineer, pharmacist, and civil engineer. Additionally, these students mentioned many famous scientists as their role models in the science domain such as Einstein, Newton, Edison, Hawking, Feynman, Faraday,

Table 5. Students with a higher degree of scientific creativity reported their family support, career images, and readings about science. (N = 12)

	Does your family encourage or support you to learn science? How do they encourage you?	Do you like to read science books? What kind of science books or magazines do you like to read?	What kind of vocation do you like most?
1	Subscribe to science magazines for me Discuss the development of science with me Buy science equipment for me	Newton magazines Biological evolution Space research	Biologist
2	Encourage me to attend scientific contests Encourage me to learn science with my passion	General geology Geological engineering Earthquake and policy Structure design for enduring earthquake Taxonomy of minerals and fossils	Geologist
3	Encourage me to attend some summer science programs Teach some scientific concepts to me	Newton magazines Little Newton magazines	Scientist
4	Share their ideas with me in science Encourage me to read scientific readings outside of school	Newton magazines Scientists	Mechanic Engineer
5	Encourage me to read scientific readings outside of school	Newton magazines Discovery channel The earth channel	Unknown
6	Buying equipments for me Encourage me to attend scientific activities	Discovery channel Story of Stars Journals of science	Doctor
7	Encourage me to read scientific readings outside of school	Newton magazines Copernicus	Mathematician Scientist

	Does your family encourage or support you to learn science? How do they encourage you?	Do you like to read science books? What kind of science books or magazines do you like to read?	What kind of vocation do you like most?
8	No support	Astronomy Astronomic Physics Psychology Philosophy	Physicist Psychologist Teacher
9	Encourage me to read science magazines Encourage me to understand the current development of biological technology	Newton magazines Scientists Biological technology	Researcher in Biological Technology
10	Encourage me to attend clubs or organizations related to science	Time of biological technology Popular Science Scientists	Pharmacist Researcher in Life Science
11	Encourage me to read some magazines Encourage me to use some daily materials to do scientific experiments	Newton magazines National geography magazines	Civil Engineer Architect
12	Buy some scientific equipment for me (i.e. microscope) Share me their previous experiences with me in science	Newton magazines Copernicus Encyclopedia in science	Specialist in Aeronautics Car Designer

Lavoisier, Copernicus, and Curie. (see Appendix O) With regard to parents' expectations about children's careers, most of their parents would respect their children's wish and let them choose what they wanted to do.

Table 6. Students with a lower degree of scientific creativity reported their family support, career images, and readings about science. (N = 12)

	Does your family encourage or support you to learn science? How do they encourage you?	Do you like to read science books? What kind of science books or magazines do you like to read?	What kind of vocation do you like most?
1	No support	Dislike	Unknown
2	No support	Dislike	Musician
3	No support	Dislike	Any but can make a lot of money
4	No support	Astronomy	Researcher
5	No support	Dislike	Unknown
6	No support	Dislike	Unknown
7	No support	Dislike	Chemical Engineer Electrical Engineer
8	No support	Dislike	Unknown
9	No support	Newton magazines	Government Employees
10	No support	Astronomy	Unknown
11	No support	Dislike	Businessman Teacher
12	Tell me to learn science will let me make money	Newton magazines Discovery Channel	Unknown

As shown in Table 6, most students with a lower degree of scientific creativity reported that they had no family support and encouragement in learning science. The only encouragement a student mentioned was that to learn science would make more money in the future. Most of these students also reported that they disliked reading science magazines and books related to science. With regard to career images, most students did not know what they wanted to do in the future. Only one student mentioned that he wanted to be a chemical engineer which is related to the science domain on their lists. Students with a lower degree of scientific creativity also reported some famous scientists as their role models in the science domain such as Einstein, Newton, Edison, and Galileo (see Appendix P). With regard to parents' expectations about children's careers, most of their parents would respect their children's wish and let them choose what they wanted to do.

Table 7 presents the differences between students with a higher degree of scientific creativity and those students with a lower degree of scientific creativity on their family support, career images, readings about science, role models, and parents' expectations. Eleven of 12 students with a higher degree of scientific creativity reported that they had much family support and encouragement, while only one of 12 students with a lower degree of scientific creativity reported the same thing. Almost all students with lower scientific creativity received no support from their family. With respect to career images, 11 of 12 students with a higher degree of scientific creativity reported that they wanted to choose careers related to science, while only one of 12 students with a lower degree of scientific creativity reported that he wanted to choose a career related to science.

In terms of magazines or books students like to read, all students with a higher degree of scientific creativity reported that they enjoyed reading magazines and books related to science, while only 4 of 12 students with a lower degree of scientific creativity reported that they enjoyed reading magazines and books related to science. As for role models in science, 10 of 12 students with a higher degree of scientific creativity and 7 of 12 students with a lower degree of scientific creativity reported that they had role models in science domain. As for parents' expectations about their children's careers, 3 of 12 students with a higher degree of scientific creativity and 2 of 12 students with a lower degree of scientific creativity reported that their parents wanted them to choose careers related to science. Generally speaking, their parents in these two groups had no particular preferences in their children's careers, and they also gave their children much freedom to choose their own careers.

Consequently, these comparisons showed that there were big gaps between students with a higher and a lower degree of scientific creativity on their family support, career images, and readings about science. In contrast, there was no differences between these two groups on role models in science and parents' expectations about children's careers.

Table 7. Comparison of frequencies of responses to the open-ended questions between students with a higher degree of scientific creativity and students with a lower degree of scientific creativity

	Family support	Readings about science	Having role models in science	Careers related to science	Parents' expectations about children's careers in science
Top 10%	**11/12**	**12/12**	**10/12**	**11/12**	**3/12**
Lowest 10%	**1/12**	**4/12**	**7/12**	**1/12**	**2/12**

Note: students with a higher degree of scientific creativity: N = 12
students with a lower degree of scientific creativity: N = 12

Students' Preferences for Science vs. Science Achievement

From the results of the last three questions added to the end of *SAI II*, students' preferences for physics, chemistry, and biology are shown in Table 8. With respect to physics, 25.6% of the students reported that they liked physics and 6.0% of the students reported that they liked physics very much, while 19.7% of the students reported that they disliked physics and 10.3% of the students reported that they disliked physics very much. Additionally, about one half of the students liked chemistry, 10.3% of the students disliked chemistry, and 3.4% of the students disliked chemistry very much. However, biology obtained higher preferences by 58.1% of the students, whereas only 6.8% of the students reported that they did not like biology.

Table 8. Students' preferences for physics, chemistry, and biology

	Like very much	Like	Neutral	Dislike	Dislike very much
Physics	7	30	45	23	12
	6.0 %	25.6 %	38.5 %	19.7 %	10.3 %
Chemistry	7	53	41	12	4
	6.0 %	45.3 %	35.0 %	10.3 %	3.4 %
Biology	21	47	41	6	2
	18.0 %	40.2 %	35.0 %	5.1 %	1.7 %

Note: N = 117

The correlations between science achievement and students' preferences for science are shown in Table 9. Students' preferences for physics, chemistry, and biology were significantly correlated with physics, chemistry, and biology achievement (0.261, 0.354, and 0.240, respectively, $p < 0.01$). With respect to the correlations among science achievement, physics, chemistry, and biology achievement significantly correlated with each other, with the largest correlation

Table 9. Intercorrelations among science achievement and students' preferences for science

	PHs	CHs	BIs	LikePH	LikeCH	LikeBI
PHs	_					
CHs	0.476**	_				
BIOs	0.210**	0.259**	_			
LikePH	0.261**	0.227*	0.106	_		
LikeCH	0.072	0.354**	0.200*	0.219*	_	
LikeBI	0.003	0.058	0.240**	0.100	0.454**	_

PHs: physics achievement, CHs: chemistry achievement,
BIs: biology achievement,
LikePH: students' preferences for physics,
LikeCH: students' preferences for chemistry,
LikeBI: students' preferences for biology,
** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

being 0.476 between physics and chemistry achievement ($p < 0.01$). In addition, students' preferences for chemistry significantly correlated with students' preferences for biology (0.454, $p < 0.01$), and students' preferences for chemistry slightly correlated with students' preferences for physics (0.219, $p < 0.05$).

However, no correlation was found between students' preferences for physics and biology.

Consequently, science achievement is significantly correlated with student preference. Science achievement in physics, chemistry, and biology are also significantly correlated with each other. The highest correlation is between physics achievement and chemistry achievement. In addition, students' preferences for biology has the highest correlation with students' preferences for chemistry, while no correlation is found between students' preferences for biology and physics.

Findings on the NSKS and SAI II

Students' Confusion on the Nature of Science

As shown in Table 10, most students in this study had no problems with the simplicity of scientific knowledge, importance of experimental tests and observations, tentative scientific knowledge, and unity of nature on the *NSKS*. For instance, 78% of the students understood that scientific laws, theories, and concepts should be stated as simply as possible. Ninety-six percent of the students thought that scientific knowledge needs be capable of experimental testing. Additionally, 96% of the students agreed that today's scientific laws, theories, and concepts may have to be changed in the face of new evidence. Ninety-two percent

Table 10. Agreement and mean scores on some statements of Nature of Scientific Knowledge Scale

A	D	Mean	Statements in Nature of Scientific Knowledge Scale (NSKS)
78 %	11 %	3.98	Scientific laws, theories, and concepts are stated as simply as possible. (+)
8 %	73 %	2.17	Scientific knowledge is specific as opposed to comprehensive. (–)
1 %	96 %	1.58	Scientific knowledge need not be capable of experimental test. (–)
75 %	10 %	3.75	Scientific laws, theories, and concepts are tested against reliable observations. (+)
96 %	0 %	4.52	Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence. (+)
92 %	3 %	4.16	There are similarities among biology, chemistry, and physics. (+)
82 %	6 %	4.01	Scientific knowledge expresses the creativity of scientists. (+)
84 %	2 %	4.13	Scientific laws, theories, and concepts represent imaginative thought. (+)
53 %	20 %	3.48	Scientific theories are discovered, not created by man. (–)
83 %	5 %	3.95	Even if the applications of a scientific theory are judged to be bad, we should not judge the theory itself. (+)
50 %	22 %	3.31	It is meaningful to pass moral judgment on both the applications of scientific knowledge and the knowledge itself. (–)
40 %	30 %	3.10	Certain pieces of scientific knowledge are good and others are bad. (–)

A: agreement (included agree and strongly agree),

D: disagreement (included disagree and strongly disagree),

(+): positive statement, (–): negative statement,

% of neutral opinions: 100% – % of agreement – % of disagreement of the students indicated that there are similarities among biology, chemistry, and physics. However, many students were confused on the creative and moral levels of the nature of science on the *NSKS*.

That scientific knowledge is a product of the human intellect is a tenet scientists want students to believe. More than 80% of the students in this study believed that scientific knowledge expresses the creativity of scientists and represents imaginative thoughts, whereas more than one half of the students (53%) thought that "scientific theories are discovered, not created by man". Two answers probably can shed some light on this controversial problem. First, these students believed that scientific theories are not created by man; and the theories are just discovered by man. In this view, students thought that scientific theories are already there and are just waiting for man to discover. Second, these students did not realize the difference between creativity and discovery. In this view, the problem will be related to meanings of words, not related to knowledge of the nature of science.

With respect to the moral level, 83 % of the students reported that even if the applications of a scientific theory are judged to be bad, we should not judge the theory itself. This result shows that most students seem to realize the difference between scientific theory itself and applications of a scientific theory. However, more than 50% of the students thought that moral judgment needs to be placed on both the applications of scientific knowledge and the knowledge itself. In other words, more than one half of the students did not understand that the cause of some mistakes is not because of scientific knowledge itself, but how man makes use of scientific knowledge. That is why 40% of the students indicated that certain pieces of scientific knowledge are good and others are bad. This result again shows that students cannot clearly distinguish between knowledge itself and applications of scientific knowledge in moral judgment.

Students' Confusion on Attitudes toward Science

Attitudes toward science is a very broad term, which involves many concepts. Results of the *SAI II* indicated students' attitudes toward scientific knowledge, attitudes toward scientific methodology, attitudes toward functions of science, attitudes toward liberal education in science, attitudes toward scientists, and personal interest toward science. Through the results of the *SAI II*, some considerable problems need to be clarified in some issues of attitudes toward science. With regard to the myth of science, Table 11 shows that 31% of the students agreed that anything we need to know can be discovered through science, and 34% of the students believed that scientists can always provide the answers. These students believed the concept of "the almighty of science and scientists" to some extent. Additionally, about 30% of the students held neutral opinions on theses two statements.

Table 11. Agreement and mean scores on some statements of Attitudes toward Science (SAI II)

A	D	Mean	Statements in Attitudes toward Science (SAI II)
31 %	39 %	2.86	Anything we need to know can be found out through science. (−)
34 %	36 %	2.95	We can always get answers to our questions by asking a scientist. (−)
68 %	12 %	3.71	A major purpose of science is to enhance the development of technology. (−)
16 %	48 %	2.63	A major purpose of science is to produce new drugs and save lives. (−)
82 %	3 %	4.02	A major purpose of science is to help people live better. (−)

A: agreement (included agree and strongly agree),

D: disagreement (included disagree and strongly disagree),

(+): positive statement, (−): negative statement,

% of neutral opinions: 100% − % of agreement − % of disagreement

With respect to attitudes toward the goals of science, 68% of the students agreed that the major purpose of science is to develop technology, more than 50% of the students did not show disagreement on the statement “A major purpose of science is to produce new drugs and save lives." and more than 80% of the students thought that a major purpose of science is to help people live better. As a matter of fact, science is devoted to providing explanations of natural phenomena, but most students in this study seemed to agree that science is devoted to serving humans. Consequently, many students held some alternative conceptions on the concept of the "almighty of science" and the purposes of science.

Summary

There were significant correlations between scientific creativity and seven selected variables including attitudes toward science, problem finding, formulating hypotheses, the nature of science, resistance to closure, originality, and elaboration. The lack of significant correlations between scientific creativity and fluency, flexibility, abstractness, and science achievement was found. Additionally, there was a significant correlation between problem finding and formulating hypotheses. All six subscales of creativity highly associated with each other. However, there were no significant correlations between attitudes toward science and science achievement.

With regard to the regression equation, the significant predictors of scientific creativity were attitudes toward science, problem finding, resistance to closure, and originality. Attitudes toward science alone accounted for 35% of the variance of the scientific creativity, and problem finding accounted for 9% of the variance of the scientific creativity. The other variables (resistance to closure and originality) contributed 4% of the variance of scientific creativity.

Comparison between students with a higher and a lower degree of scientific creativity in open-ended questions indicated significant differences between these two groups on the variables of family support, career images, and readings about science. However, there were no differences between theses two groups on role models in science and parents' expectations about children's careers. In terms of preferences for science, students' preferences for biology were significantly correlated with their preferences for chemistry. Also, students' preferences for science significantly correlated with their science achievement. Based on the results of *NSKS* and *SAI II*, students were confused in the creative and moral levels on *NSKS* and the concept of "the almighty of science" and the purposes of science on *SAI II*.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter offers (1) discussion and conclusions (2) implications on theory and pedagogy, (3) limitations of the study (4) recommendations for science curriculum, instruction, and future research.

Discussion and Conclusions

As mentioned earlier, there is little research attention that has been paid to students' scientific creativity, hence the purpose of this study was to explore the correlation between students' scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, and attitudes toward science. Correlations among scientific creativity and these variables may help understand the nature of students' scientific creativity and determine significant predictors of eleventh-grade students' scientific creativity in the process of learning science. The research questions posted at the beginning of the study are addressed as follows:

Research question 1: Are there significant correlations among scientific creativity and selected variables including creativity, problem finding, formulating hypotheses, science achievement, the nature of science, attitudes toward science in the process of learning science by eleventh-grade students?

There were significant correlations between scientific creativity and seven selected variables including attitudes toward science, problem finding, formulating hypotheses, the nature of science, resistance to closure, originality, and elaboration. The lack of significant correlations between scientific creativity and fluency, flexibility, abstractness, and science achievement was found. Additionally, there was a significant correlation between problem finding and formulating hypotheses. All six subscales of creativity highly associated with each other. However, there were no significant correlations between attitudes toward science and science achievement.

Attitudes toward Science

Positive attitudes toward science play a major role in affecting students' scientific creativity in this study. Numerous researchers suggested a strong connection between positive attitudes and creativity. Duke (1972) argued that there is no clear correlation between creativity and personality type, intelligence, experience, and knowledge, but there is a most important relationship between attitudes and creativity. People who are identified as more intrinsically motivated toward their work have been found to produce work rated as more highly creative. Therefore, positive attitudes enhance students' intrinsic motivation that lays a base for creative achievement (Collons & Amabile, 1999). Additionally, creators such as professional artists and research scientists tend to be more intrinsically motivated toward their work than the general people (Amabile et al., 1994).

As for the correlation between attitudes and cognitive variables such as science achievement, there was no correlation between attitudes toward science and science achievement in this study. In fact, the available evidence indicated a weak relationship between attitudes and cognitive variables. Researchers found no differences between high IQ and low IQ children in their attitudes toward science and no relationships between science achievement and attitudes toward science (Clarke, 1972; Wynn & Bledsoe, 1967). A negative relationship between grades and attitudes toward science was found (Baker, 1985; Richardson & Stanhope, 1971).

In this study, no significant correlation between science achievement and attitudes toward science was found; however, students' preferences for physics, chemistry, and biology were significantly correlated with their achievement in physics, chemistry, and biology respectively. In other words, students with higher preferences for physics possibly perform better than students with lower preferences on physics achievement. However, attitudes toward science, in a very broad sense, involves attitudes toward the whole science domain, not just toward physics, chemistry, biology, or any other single science subject matter. For instance, a student who likes chemistry and biology might dislike physics, but the student may have a positive attitude toward science. Moreover, attitudes toward science not only include students' interest or preferences for science, but also students' attitudes toward general images of science and scientists.

According to the difference between preferences for a particular science domain and attitudes toward science, science may be divided into physical science and biological science. Schibeci (1984) who summarized 200 studies related to attitudes research in science, claimed five conclusions. One of the five conclusions was that 'science' must be divided into physical science and biological science in doing research of attitudes toward science. The reason for Schibeci's conclusion is that students' attitudes toward the biological sciences appear generally to be more favorable than those attitudes toward the physical sciences. In this study, a high correlation between physics and chemistry achievement was found, therefore supporting Schibeci's conclusion. In fact, certain curriculum designs in many countries subscribe to the same theory. Introductory physical science and life science are offered first, before entering physics, chemistry, and biology.

However, students' preferences did not show the same pattern as science achievement in this study. For instance, students' preferences for chemistry significantly correlated with their preferences for biology, but not with preferences for physics. It leads us to speculate that if the similarity between chemistry and biology did not receive enough attention as much as the similarity between chemistry and physics. Moreover, this result might shed some light on the appropriateness of dividing science into physical science and biological science on attitude research.

With respect to students' responses to some items of *SAI II*, more than one third of the students agreed that everything can be understood through the study of science and scientists can always answer our questions; only one third of the students disagree at this statement. As for attitudes toward the purposes of science, most students believed that science is to serve human beings and to improve the quality of life. In sum, many students had alternative images concerning the concept of "the almighty of science and scientists," and the purposes of science. Therefore, it is meaningful to reconsider the goals of science education. The goals for school science in the National Science Education Standards (1996) are as follows: (1) knowing and understanding the natural world; (2) using scientific process and principles to make personal decisions; (3) debating about matters of scientific and technological concern; (4) increasing economic productivity through the use of the knowledge and skills of the scientifically literate person in their careers.

According to these goals for school science, students may not obtain a complete and clear image about the purposes of science through formal schooling.

In fact, students may more easily receive some messages such as new drugs saving lives or new cloning techniques changing the way people live from TV programs, newspapers, the Internet, and many other mediums. These messages may encourage students to believe that science probably can solve all problems they face. The question is, what kind of image of science do schools project during formal education? Students should be taught both the benefits and disadvantages resulted from science, and students should understand how to balance these two sides. Additionally, students should be taught that science is devoted to providing explanations of natural phenomena rather than just devoted to serving human beings. Finally, teachers should avoid exaggerating the concept of "the almighty of science" in order to motivate students to learn science.

Problem Finding vs. Formulating Hypotheses

Problem finding, increasingly recognized in theories of creativity, has been viewed as the most important component in the creative process (Getzels, 1975). Some researchers reminded us that problem finding contributes to meaningful scientific creativity causing scientific progress (Mackworth, 1965; Snow, 1960). Additionally, Arlin (1975) claimed that problem finding is the fifth stage of adult cognitive development, and may extend beyond the level of formal operations. In other words, the problem-solving stage is a necessary but not sufficient condition for the problem-finding stage. In this study, problem finding significantly correlates with scientific creativity, therefore it is a very important ability for predicting students' scientific creativity. This finding certainly supports the importance of problem finding in science learning and scientific creativity. As we know, the concept of problem finding originated in the science field. Nevertheless, it never echoes strongly in the field of science and teaching. In science classrooms, teachers tend to provide too much information for students to gain expertise in solving presented and well-defined problems, causing them to ignore ill-defined problem situations and the ability of problem finding. In other words, students are rarely given the opportunity to pose problems of their own design (Moore, 1994). Additionally, current mental tests or science achievement tests are biased against problem finders because they inevitably favor the problem solvers.

With respect to the relationship between problem finding and formulating hypotheses, there was a controversy among research literature. Hoover (1992) defined scientific problem finding ability as the subjects' abilities to formulate hypotheses in a given realistic situation. There were significant correlations between a measure of creativity and the ability of formulating hypotheses in gifted fifth-grade students in Hoover's studies. In contrast, Subotnik and Steiner's (1994) longitudinal study about Westinghouse Science Talent Search winners found that there were no significant differences among the three groups: problem finders, presented problem solvers, and non-researchers on *Formulating Hypotheses Test*. The result of Subotnik and Steiner's research supports the idea that there is no positive correlation between the ability of problem finding and the ability of formulating hypotheses.

In this study, a significant positive correlation between the ability of problem finding and the ability of formulating hypotheses was found. Formulating hypotheses accounted for 20% of the variance of problem finding.Formulating hypotheses is considered as a diffuse, nonlinear, and imaginary process, not guided by explicit methodological rules (Rachelson, 1977). Accordingly, formulating hypotheses may share part of the same nature with problem finding in science learning. Therefore, it is expected that formulating hypotheses and problem finding are associated with each other. From this study, the ability of problem finding and the ability of formulating hypotheses significantly correlated to some extent; however, it cannot be concluded that the ability of problem finding and the ability of formulating hypotheses are the same abilities.

Scientific inquiry is usually defined as a two-component problem-solving process. These two components, formulating hypotheses and testing hypotheses, share a complementary relationship with each other (Rachelson, 1977). The majority of work in science education would be performed in the context of testing hypotheses; limited work is conducted on formulating hypotheses. However, the ability to formulate hypotheses has become an essential element of science education. For instance, the ability to formulate hypotheses is one of the assessment criteria of the National Science Curriculum in England and Wales (Swatton, 1992). Additionally, NRC (1996) contend that all students in grades 9-12 should develop abilities necessary to do scientific inquiry and understanding about scientific inquiry. One of the abilities necessary to conduct scientific inquiry is that students should formulate testable hypotheses.

After formulating hypotheses received enough attention, it is necessary to ponder the role of problem finding in the process of scientific inquiry. Scientific inquiry should include problem finding, formulating hypotheses, and testing hypotheses. In most science classroom instruction, problem finding is often ignored during the process of scientific inquiry, especially in countries with high stakes testing. The high stakes testing stifles opportunities for students to think about finding problems. Students usually solve problems that are teachers generated. It is believed that this kind of learning culture also limits the development of students' creativity.

Creativity

In the field of creativity, divergent thinking has been treated as a kind of shorthand for creativity; therefore many researchers have used divergent thinking tests as an index or indicator of creativity. Some researchers claimed that creativity is something beyond domain-dependent knowledge and skills because of the theory of divergent thinking (Hennessey & Amabile, 1988; Trefinger, 1986). Indeed, divergent thinking skills are easily assumed to be transferable from one task to another (Baer, 1993). However, Runco (1993) reminded us that divergent thinking is not synonymous with creative thinking. Divergent thinking tests are frequently used because they are easily assessed, quantified, and adapted for use in the classroom. Runco also indicated that divergent thinking may be involved in some creative performances, but it may not be required in all domains. In this study, scientific creativity significantly but lowly correlated with only three (resistance to closure, originality, and elaboration) out of six subscales of divergent thinking. That is, some subscales of creativity may not be required in scientific creativity performances.

However, divergent thinking lowly correlated with scientific creativity in this study. If divergent thinking is a very good index of creativity, it seems that there was no high correlation between creativity and scientific creativity in this study. In other words, the theory of creativity as a general intellectual trait is doubtful. Advocators of domain specificity claimed that people are creative within particular domains. For instance, Runco (1987) found low correlations among creative performances of fifth through eighth-grade students in different domains. As a matter of fact, knowledge has been received much attention in the theory of domain specificity. The tension between knowledge and creativity has been explained as a U shape. That is, maximal creativity occurs with some middle range of knowledge (Weisberg, 1999).

Renzulli (1982) also had a similar theory that above-average general ability and knowledge are required for giftedness. Accordingly, if one has above average knowledge, knowledge no longer plays a major role in creative performance. In this study, there was no significant correlation between science achievement and scientific creativity. Science achievement is the sum of a series of diagnostic and summative science content tests at school in Taiwan. Therefore, science achievement supposedly represents the levels of students' science content knowledge. Students with high science achievement did not perform well in scientific creativity in this study. Although this result did not directly support the threshold theory between knowledge and creativity, it is certain that science achievement should not be used as an index for selecting giftedness in science.

In sum, the low correlation between scientific creativity and creativity in this study probably indicates some weakness in the research on scientific creativity. For example, Eichenberger (1978) developed an instrument to measure students' scientific creativity in physics. Eichenberger used the *Torrance Tests of Creative Thinking* (*TTCT*) as an instrument for validating his own instrument. Due to the low correlation between scientific creativity and creativity in this study, it is not appropriate to use the *TTCT* to validate an instrument of scientific creativity. Musil (1982) also claimed that specific divergent thinking tests have to be designed to improve the prediction of specific types of creativity. Therefore, it is concluded that scientific creativity cannot be measured by any kind of general creativity instrument in this study. Additionally, if an instrument designed specifically for a particular domain such as physics, it cannot be generalized to other domains such as chemistry because of the involvement of a high level of domain knowledge. At this time no appropriate commercial instruments are available to measure students' scientific creativity.

Nature of Science

Students' knowledge about the nature of science correlated minimally with students' scientific creativity in this study. Even though the nature of science is not a significant predictor of students' scientific creativity, understanding the nature of science is a central component of national science education reform efforts. Some researchers suggested tension between science educators and philosophers of science on the nature of science tenets. Other researchers believed that a reasonable consensus exists on many lower-level points (in elementary and secondary school science) about nature of science (Alters, 1997; Matthews, 1994).

In this study, a consensus on some statements about the nature of science (*NSKS*) was found among participants. Most students agreed that scientific knowledge is subject to review and change; scientific knowledge is comprehensive as opposed to be specific; scientists test their explanations of nature through observations, experiments, and theoretical models; and the evidence for scientific knowledge must be repeatable. However, students in this study were confused about the creative and moral levels of the nature of science. With respect to the creative level of the nature of science, most students thought that scientific knowledge expresses scientists' creativity and imaginative thoughts, but some of them also agreed that scientific theories are discovered, not created by man. A conflict between these two responses is noted. It is meaningful to interpret this conflict from different perspectives. First, students believed that scientific knowledge or theories are present and waiting for humans to discover them. However, the process of discovery also involves scientists' creativity and imagination.

Second, students in this study did not sufficiently understand the difference between discovering and creating science knowledge and theories. Therefore, the meanings of these two words may have confused the students. Creativity is defined as the phase of generation, construction, or combinational play, while discovery involves the interpretation or exploration of the structures produced during combinational play or simply the interpretation of existing structures (Roskos-Ewoldsen et al., 1993). On the other hand, some researchers have a broader view about discovery, and describe the discovery task as both generation-construction and exploration-interpretation processes (Finke, 1990; Roskos-Ewoldsen et al., 1993). Accordingly, even researchers have difficulty agreeing on the difference between discovery and creation. Indeed, teachers and textbooks do not distinguish the meanings among the concepts such as creating, discovering, inventing, forming, and formulating carefully. For clarifying this confusion, students need to be introduced to proper definitions or basic concepts about the philosophy of science. Moreover, teachers have to be careful about their wordings so as not to mislead students about the nature of science.

With regard to the moral level in the nature of science, about half of the students thought that moral judgment can be passed on both the applications of scientific knowledge and the knowledge itself. Because students could not correctly distinguish between knowledge itself and applications of scientific knowledge in a moral judgment, they attributed some inappropriate applications of scientific knowledge to science knowledge itself. Therefore, they had an alternative conception that some scientific knowledge is good and some is bad.

Moral judgment will be a very important issue of science education in the future. Nowadays, scientific knowledge overwhelmingly influences the whole world. Some applications of scientific knowledge probably caused the collapse of human's moral values dealing with issues such as cloning, genetic engineering, and the use of nuclear or biochemical weapons. Even scientists cannot imagine where scientific knowledge will lead us since the fast growth of science and technology seems to make everything possible. Students must realize that scientific knowledge in itself is not bad. The problem may arise from how human beings use scientific knowledge. In addition, students must have an understanding that science is aimed at approaching the reality and the truth, but applications of scientific knowledge need to be under control. Training in moral judgment will help students use scientific knowledge more appropriately. For example, using Science-Technology-Society curriculum design and role playing teaching strategy will lead students pay attention on moral values in science issues.

Research question 2: What are significant predictors of scientific creativity in the process of learning science by eleventh-grade students?

Four variables (attitudes toward science, problem finding, resistance to closure, and originality) were significant predictors of students' scientific creativity. These four variables accounted for approximately 48% of the variance of scientific creativity. In terms of contributions of the individual predictors, the attitudes toward science alone accounted for 35% of the variance of scientific creativity, and problem finding accounted for 9% of the variance of scientific creativity. The other variables (resistance to closure and originality) contributed only an additional 4%.

This result echoes Amabile's (1983) componential conceptualization of creativity, one of the first and most influential models in determining performance of creativity. Amabile's three components of creativity performance include task motivation, domain-relevant skills, and creativity-relevant skills. First, task motivation represents the individual's baseline attitude toward the task; therefore, attitudes toward science in this study can be similar to task motivation. Amabile claimed that task motivation is the most important determinant of the difference between what a person can do and what he will do. 'What a person can do' is determined by the level of domain-relevant and creativity-relevant skill and 'what a person will do" is determined by these two skills with an intrinsically motivated state. In this study, the highest correlation between scientific creativity and attitudes toward science can support this determinant theory. That is, positive attitudes toward science is a threshold for approaching scientific creativity.

Second, domain-relevant skills include familiarity with factual knowledge of the domain, technical skills, and special talent in the domain. In the science domain area, problem finding requires cognitive ability and higher order thinking skills in the process of scientific creativity. Therefore, the ability of problem finding can be classified into domain-relevant skills of Amabile's theory in this study. Third, resistance to closure and originality can be categorized into creativity-relevant skills of Amabile's theory in this study. The four significant predictors of scientific creativity in this study are consistent with Amabile's three components of creative theories to some extent.

Research question 3: Are students with a higher degree of scientific creativity different from those students with a lower degree of scientific creativity on variables such as family support, career images, readings about science, role models, and parents' expectations?

Comparison between students with a higher and a lower degree of scientific creativity in open-ended questions reveals significant differences between these two groups on the variables of family support, career images, and readings about science. However, there were no differences between theses two groups on role models in science and parents' expectations about children's careers.

Many aspects of families such as encouragement, training, genetic history, the age of parents when children are born, birth order, the kinds of jobs that parents hold, amount of family resources, religious beliefs, and parental loss have been noted in the research of creativity performance (Feldman & Piirto, 1994). However, there were few clear-cut explanations for the relationship between creativity performance and these factors, except family support.

In a study of talented mathematicians and composers, Bloom and Sosniak (1981) found that the parents were usually intensely involved in the child's talent development from the beginning. They offered encouragement, enthusiasm, and passionate involvement in the talent field. When their children's talent became increasingly evident, they would spend large amount of money and efforts on finding the most qualified tutors for their children. Bloom (1985) found that performers at the highest level in fields such as piano, neurosurgery, swimming, and mathematics typically had a family history in which at least two generations participated in a similar field. In other words, being raised in an environment where there is encouragement to participate in it seems to be very important.

In this study, there were large differences of family support between students with a higher and a lower degree of scientific creativity. Eleven out of 12 students with a higher degree of scientific creativity reported strong family support and encouragement, while only one out of 12 students with a lower degree of scientific creativity reported family encouragement. This result supports the importance of family encouragement as reported by Bloom and Sosniak in creativity performance. In addition, Tardif and Sternberg (1988) indicated that having a future career image and definite role models, mentors, and paragons were important factors influencing the development of creators in many fields. In this study, there were large differences on having future career images between students with higher and lower scientific creativity. Almost all students with a higher degree of scientific creativity would probably select careers related to science, whereas almost no students with a lower degree of scientific creativity would likely select careers related to science. This result also supports the importance of future career images mentioned by Tardif and Sternberg (1998).

With respect to having role models, there were no differences of the quantitative data between these two groups. Ten out of 12 students with a higher degree of scientific creativity reported that they had role models in the science domain, and 7 out of 12 students with a lower degree of scientific creativity also reported that they had role models in the science domain. However, there were differences on the qualitative data between these two groups. Role models mentioned by students who demonstrated a lower scientific creativity included

Einstein, Newton, Edison, and Galileo. It is interesting to note that these scientists were usually introduced in students' textbooks. As for students with a higher degree of scientific creativity, they mentioned various scientists as their role models, many of whom were not introduced in high school textbooks. In addition to Einstein, Newton, and Edison, students also mentioned Nobel, Curie, Faraday, Feynman, Hawking, Copernicus, Lavoisier, and some famous geologists in Taiwan. The possible reason is that students with higher scientific creativity spend more time reading outside of school. Thus, they may understand scientists' efforts and accomplishments more deeply. In this study, all students with a higher degree of scientific creativity reported that they enjoyed reading science books and magazines, but only 4 out of 12 students with a lower degree of scientific creativity reported that they enjoyed reading science books. This difference of readings outside of school between these two groups probably may explain why role models mentioned by these two groups are so different.

Finally, parents' expectations for children's careers did not show any difference between these two groups. One may infer that parents' expectation is an extrinsic motivation for students. Therefore, parents' expectation is not as powerful as students' own career images since creativity will most likely have resulted from an intrinsically motivated state.

Implications

Theoretical Implications

Creativity plays a major role in the scientific enterprise and science teaching. There are few studies that focus on exploring students' scientific creativity and ways to improve or foster students' creativity in science learning. This study provides a more sophisticated understanding of the nature of scientific creativity through clarifying significant correlations between scientific creativity and selected variables. In previous research, some researchers used cognitive perspectives to explore students' scientific creativity. For instance, they used problem finding or formulating hypotheses as a criterion for assessing scientific creativity (Hoover, 1992; Hoover & Feldhusen, 1990). Because of the importance of attitudes toward science based on the results of this study, it is recommended that researchers should employ more affective aspects to approach students' scientific creativity.

In addition, it is not appropriate to use only science achievement and IQ tests to identify students' creative potential for special programs. Self-reported procedures in creative activities and past creative accomplishments, and peer or teacher nomination used in this study were considered as more appropriate tools for assessing students' scientific creativity. Integrating students' creative products and creative characteristics in this study helps us use an objective approach for assessment. In addition, information from students, and their peers and teachers will help construct a more holistic and integrative interpretation of students' scientific creativity. For admission of students to special scientific gifted programs, science test scores and IQ scores can be used to screen students who score in the lowest ranges. After the screen-out process, it is suggested that decisions should be based on other indicators of potential for superior performance including aptitude scores, recommendations from teachers, recommendations from guidance counselors, involvement in extracurricular activities and accomplishments.

The important determinant of creative behaviors is a collage of personality traits, preferences, and attitudes as well as a set of cognitive skills and creative skills. In addition, the social environment also supports and stimulates creative efforts. However, a unifying theoretical conceptualization of creative behavior such as Amabile's (1983) componential theory of creativity, is necessary to further promote research in creativity. The results of this study support Amabile's componential theory of creativity. In other words, Amabile's three components (domain-relevant skills, creativity-relevant skills, and task motivation) can also be generalized to the research of scientific creativity. These three components are not separate. Creativity will be highest among individuals in the area where the three components share their greatest overlap. That is, individual's domain-relevant skills overlap with the individual's strongest intrinsic motivation and creative thinking skills. All these classes of factors in Amabiles's models may serve a heuristic function in guiding future research.

Pedagogical Implications

Of pedagogical significance, the findings of this study demonstrate a strong correlation between scientific creativity and variables such as attitudes toward science, problem finding, formulating hypotheses, resistance to closure, originality, and elaboration. It is suggested that science teachers should be encouraged to view scientific creativity as an ability that can be taught rather than an innate, insightful or fantastic ability. Therefore, students' scientific creativity can be enhanced through various means in classroom science teaching.

Attitudes toward science is an essential variable in students' scientific creativity performance. Therefore, to stimulate students' curiosity, interest and positive attitudes toward science is a challenge for teachers. Bruner (1966) identified curiosity, a biological drive, as the best type of intrinsic motivation. Ross (1981) claimed that knowledge and inquiry depend only on primordial mysteries. Therefore, bringing curiosity and mystery into the classroom could be considered as a starting point in teaching and learning science.

Problem finding is an important cognitive skill in science leaning. Nonetheless, curriculum materials and teachers' questions still state problems for students to resolve. The ability to identify and formulate a problem is seldom taught during the process of solving problems. Therefore, teachers should understand the importance of problem finding in promoting scientific creativity. How science teachers treat students' problems may well determine the degree of creativity that students may develop. Kay (1994) suggested that the first step to find problems is collecting a number of interesting facts about a chosen topic. Second, memorization must be appropriately discarded from science teaching and replaced by understanding through problem finding and problem solving. Hoover and Feldhusen (1994) also suggested that teachers should provide students with opportunities to develop well-structured knowledge bases organized around major unifying themes rather than the accumulation of isolated facts.

In addition to knowledge organization, the types of problems deserve much more attention. Open-ended interdisciplinary problem situations mentioned by Moravcsik (1981) should be introduced in science classroom teaching since these problem situations will give students enough room and freedom for thinking, exploring, and creating. Also, students can use a variety of knowledge to explore their problems in interdisciplinary problem situations. As for experimental methods, Washton (1967) reminded us that we should let students perform scientific experiments before we teach them scientific concepts. Open-ended laboratory situations will have students design and try out experiments to test their own hypotheses. Finally, teachers should assist students to plan, monitor, and evaluate their learning and findings in the process of scientific inquiry.

Generally speaking, there were many teaching strategies for fostering creativity. For example, Cropley (2001) mentioned brainstorming, synectics, creative problem solving, morphological methods, bionics, imagery training, and mind maps for fostering creativity in many different situations. Creative Problem Solving (CPS) was developed by Treffinger and colleagues (Treffinger, Isaksen, & Dorval, 1995). CPS, including six steps (mess finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding), shares the similar nature to the three important abilities (problem finding, formulating hypotheses, and testing hypotheses in the science domain) mentioned by this study. First of all, they have the same initial step, problem finding, which is the heart of creativity. Second, formulating hypotheses can be similar to solution finding because formulating hypotheses is one of the methods for finding solutions. Third, testing hypotheses can be similar to accepting findings since hypotheses are either accepted or refused, after testing them in the science domain. Therefore, teachers may use the CPS teaching strategy for enhancing students' scientific creativity.

Limitations of the Study

Research in scientific creativity generally is divided into four classifications: product, process, person, and environment. Because the environmental variable is too complex and the process variable needs to be explored in a longitudinal study, this study focused on creative products and personal characteristics for measuring students' scientific creativity. These two different dimensions of assessment including products and personal characteristics may not represent a complete picture of scientific creativity, but these two dimensions do offer objective and quantitative data based on current available instruments.

Since the samples in this study were not randomly selected, limitations of demographic characteristics and geographic locations may affect the generalization of analyses and conclusions in this study. In other words, conclusions generated from this study may not be generalized to other high school students in Taiwan. In addition, the study was conducted in biology classes, so the conclusions of this study may not be necessary generalized to other science classes such as chemistry or physics. In addition, correlational research does not determine a causal relationship between variables. Hence, even though the findings of this study suggest significant correlations between students' scientific creativity and selected variables such as attitudes toward science, problem finding, resistance to closure, and originality, it would still remain uncertain to conclude that these variables initiated change in students' scientific creativity and remain much possibilities for more deep studies in the future.

Recommendations

Curriculum

Education needs to bring about the required talent in terms of creative ability. Specifically, science can no longer be taught just to prove known facts or perform cookbook type laboratory experiments. The answers to questions in cookbook type laboratory experiments are usually found in the textbook without even actually performing such experiments. Therefore, new curricula are very much needed, including changes in scientific inquiry process and open-ended laboratory experiments.

The process of scientific inquiry should be emphasized on three different levels: problem finding, formulating hypotheses, and testing hypotheses. Curriculum materials usually state the problems for students; therefore students are not provided opportunities to develop complete learning and thinking skills in scientific situations related to the real world. Specifically, formulation of a problem is the most important opportunity for students to develop creativity in science. Therefore, curriculum materials should be designed to balance students' abilities including problem finding, formulating hypotheses, and testing hypotheses.

In addition, experimentation in textbooks is often presented as a method or a tool for verifying scientific knowledge and theories. Students' experiment manuals are similar to cookbooks. To be successful, students just need to follow the manual step by step. In this way, although students still do "hands-on" experiments, they do not need to use their "brains" for thinking. The experiments are hands-on, but not minds-on. In classroom teaching, teachers usually teach concepts first and then have students conduct experiments to verify the information. This kind of experimenting does not completely reflect the actual process of scientific discovery. Students may be misled by the process of verification and then have ignored the discovery function of experiments. Therefore, students may obtain some alternative conceptions about the nature of science and scientific development that are misleading.

Lehrer, Schauble, and Petrosino (2001) emphasized that experimentation should be presented as one means of constructing or refining a model, but not as a method. In other words, the importance of models and representations need to be emphasized more than hypothesis testing. As a matter of fact, a good curriculum or experimental design should be more likely close to real situations in scientific development. For instance, we may have students do experiments before teachers teach them the necessary concepts. In other words, it is more meaningful to encourage students to discover those concepts through experiments than through spoon-feeding them. It is recommended that open-ended laboratory experiments should be designed to enhance students' creative potential by providing students with flexible time and room to design their own experiments. Through comparing with other peers' results of experiments, students will learn concepts from doing these experiments.

School curricula have undergone crucial change in Taiwan. A nine-year continuous curriculum will be implemented during the next few years. A "nine-year continuous" curriculum means that the curriculum from elementary school through junior high school (a total of nine years) is completely continuous and integrated. Biology, physics, chemistry, earth science, and many others related to science were integrated into one discipline named "nature and technology". This kind of integrated curriculum will help students break the boundaries between various science domains. One of the goals of the new curriculum is to cultivate students' independent thinking, promote students' abilities of problem solving, and enhance students' creative potential. As a matter of fact, Tang (1986) suggested that broad background in several scientific fields and crossed-disciplinary knowledge indeed enhance the creative powers and make novel connections for students.

In addition, moral judgment should be added into science curriculum. New scientific knowledge and applications of scientific knowledge need to be presented to students, but benefits and disadvantages of applications of scientific knowledge should also be introduced to students at the same time. For instance, some research such as cloning humans has been banned in some countries, but a few scientists are still performing their research in secret. This is not just about scientific knowledge, but about moral values. Curriculum should be prepared for future scientists with humane concerns, so students need to have appropriate trainings in moral judgment when encountering unknown applications of scientific knowledge.

Instruction

It will be very difficult for teachers to promote students' scientific creativity unless they are willing to examine their own teaching philosophy. For instance, teachers may ask themselves if they are secure and do not feel threatened when students challenge their ideas; they may ask if they give reassurance to students' intelligent guessing and novel ideas although they may not be correct answers. In order to promote students' creativity, teachers should provide students opportunities to ask thought-provoking questions during a lecture, discussion, recitation, and laboratory. More questions at the beginning sessions should come from students rather than from the teacher. Additionally, teachers themselves should use the question mark more than the exclamation mark if they want to teach for creativity and inquiry.

Teachers should encourage students to choose their own topics for individual or group projects. Having students do something they love will maximize their creative potential. If students request substitute assignments with a creative potential, science teachers should not insist on giving identical assignments. Teachers' insistence will diminish the possibility of creative efforts in science. Often, teachers have to face the task of attempting to sustain students' intrinsic motivation. On the other hand, teachers need to control extrinsic constraints. It is impossible to eliminate all extrinsic constraints in most academic settings. At least teachers can provide students with a psychologically safe environment, and offer students freedom, security, and time to think about and develop their ideas.

In addition, the guidance and support from a more experienced senior person often plays a crucial part in the development of creativity (Tardif & Sternberg, 1988). Therefore, apprenticeship should be added in science teaching.

In addition, teachers should encourage students to work with other peers in small groups. The group is catalytic to the transformation of style and content, and discussions among peers may stimulate students' divergent thinking and creative potential.

With respect to readings about science, teachers should encourage students to read more science books and publications outside of school. Reading current general science magazines will help students understand the development of the latest scientific knowledge. For example, Newton, Little Newton and Scientists were very popular magazines in Taiwan. Students can receive scientific knowledge outside of school through reading these magazines. Reading scientists' autobiographies will help students understand and gain an appreciation of scientists' efforts, lives, and accomplishments, and also help students understand the development of science history. Students who are inspired to learn science will also want to search different sources to acquire the answers to their own questions. Therefore, teachers should give students opportunities to find answers for their own questions. In creativity, there should be given some additional opportunity to explore additional knowledge rather than teachers resolving the questions by providing a final answer.

Future Research

Torrance (1988) presented an interesting analogy: creativity is like shaking hands with tomorrow. Looking forward, the forces of searching the nature of creativity may come from different perspectives. Some recommendations for future research are offered as follows:

1. In this study, creative products and creative personal characteristics were considered as external criteria for measuring students' scientific creativity. Although these two instruments are quite objective and reliable, they still do not depict a thorough picture of scientific creativity performance. Therefore, future research may focus on developing reliable instruments related to creative processes and creative environments. It is meaningful to offer different approaches to the identification of creative talent.
2. The participants in this study were male, eleventh-grade students in three different biology classes. Also, the content of problem finding and formulating hypotheses was related to the field of biology. It would seem worthwhile to replicate this research with different groups of students. For example, future research may focus on gender differences, different levels of students, and different content knowledge (physics, chemistry, or earth science) for problem finding and formulating hypotheses.

3. This study focused on a macroscopic and quantitative approach to exploring scientific creativity and sought to find a general framework and significant predictors of students' scientific creativity. Future research may add a more microscopic and qualitative approach to observe students' creative processes. For example, to understand students' conceptual combination, conceptual expansion, conceptual changes, analogy reasoning, and mental models in creative processes will help us better understand the nature of scientific creativity.
4. The results of this study emphasized that scientific inquiry should include three different abilities: problem finding, formulating hypotheses, and testing hypotheses. Future research may use a more balanced teaching strategy including these three abilities in a longitudinal study and observe if students trained by this kind of teaching strategy will result in higher scientific creativity.
5. Problem finding is an important source of scientific creativity in this study. When we advocate the importance of problem finding in science learning, we can easily find that many topics (problems) of award-winning students in science contests are receiving help from professionals outside of school or from family. Two questions emerge for future studies. One question, "Are these students really talented if they received extensive

assistance from professionals?" The other question, "What role do professionals and family play in the process of students' finding problems?" The results from these studies will help to clarify the nature of students' scientific creativity and assist others to rethink the fairness on current assessments for selecting gifted students in science.

6. In this study, family support information was qualitatively presented; therefore a clear correlation between students' scientific creativity and family support cannot be drawn. However, the gap between students with a higher degree of scientific creativity and those with a lower degree of scientific creativity was found on the variable, family support. Therefore, family support may be a major factor in affecting student's scientific creativity performance. In the future, it will be very useful to design a questionnaire specifically for investigating students' family support in science. Through this kind of questionnaire, we can probably investigate, in a meaningful way, the correlation between the extent of family support and students' scientific creativity.
7. Nowadays, many techniques allow us to conceptualize mental activity by measuring blood flow or the glucose metabolic rate (GMR) in the brain. GMR is an index of how activated a region of the brain is. The general finding is that the more intelligent one is, the less activated one's brain is

(Haier, Siegel, Tang, Abel, & Buchsbaum, 1992). As for creativity research, these techniques have not yet been used to study creative thinking. Therefore, a future study may be the research about how activated one's brain is when a more creative one faced with a problem. These future studies on neuropsychology will help cognitive researchers and educational researchers in the creativity field better understand the nature of creativity. Teachers then may use different strategies to stimulate students' creativity based on physiological evidence.

The world looks so different after learning science.

For example, tress are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree. And in the ash is the small remnant of the part which did not come from air, that came from the solid earth, instead.

These are beautiful things, and the content of science is wonderfully full of them. They are very inspiring, and they can be used to inspire others.

Richard Feynman

APPENDICES

Appendix A

Consent Form

Exploring Students' Scientific Creativity in Learning Science

Your child is invited to participate in a study of exploring students' scientific creativity in learning science. My name is Jia-Chi Liang and I am a doctoral candidate in the Science Education Program at the University of Texas at Austin, Austin, Texas, U.S.A. This study is being conducted for my dissertation research for the completion of my Ph.D. degree. I am asking for permission to include your child in this study because I hope to find some significant predictors of students' scientific creativity in learning science. I expect to have approximately 120 students in the study.

If you allow your child to participate, I will ask your child to complete three questionnaires and one test. The completion of the assessments will take about 100 minutes, and they will have 10 minutes break in the middle of doing assessments. There is no risk in answering these assessments. To examine the correlation between scientific creativity and some selected variables such as attitudes toward science, creativity, and nature of science, your child's identification numbers in school will be used on the assessments. Great care will be used to maintain confidentiality, and your child's identification numbers in school will only be used to match assessments. This study will be a good opportunity for your child to be more aware of which factors influencing his or her scientific creativity in science learning process.

Any information that is obtained in connection with this study and that can be identified with your child will remain confidential and will be disclosed only with your permission. His or her responses will not be linked to his or her name or your name in any written or verbal report of this research project.

Your decision to allow your child to participate will not affect your child's grade in any class at school, nor will influence your or his or her present or future relationship with the teacher, the school, or The University of Texas at Austin.

If you have any questions about the study, please ask me. If you have any questions later, you may contact me at 002-1-512-320-8723 or through E-mail: jiachi1219@mail.utexas.edu. You may also contact my supervisor Professor James Barufaldi at 002-1-512-471-7354 or through E-mail: jamesb@mail.utexas.edu. If you have any questions or concerns about your child's participation in this study, call Professor Clarke Burnham, Chair of the University of Texas at Austin Institutional Review Board for the Protection of Human Research Participants at 232-4383.

You will be given a copy of this consent form for your records. You are making a decision about allowing your child to participate in this study. Your signature below indicates that you have read the information provided above and have decided to allow him or her to participate in the study. If you later decide that you wish to withdraw your permission for your child to participate in the study, simply tell me. You may discontinue his or her participation at any time.

____
Printed Name of Child

________________________________ ________________
Signature of Parent(s) or Legal Guardian Date

________________________________ ________________
Signature of Investigator Date

I have read the description of the study titled exploring students' scientific creativity in learning science that is printed above, and I understand what the procedures are and what will happen to me in the study. I have received permission from my parent(s) to participate in the study, and I agree to participate in it. I know that I can quit the study at any time.

________________________________ ________________
Signature of Minor Date

Appendix B

Creativity Rating Scale

This scale is designed to obtain peer estimates of a student's characteristics in the areas of creativity. Please read the statements carefully in science context and place your choice in the appropriate place according to the following scale of values: 1. If you have seldom or never observed this characteristic. 2. If you have observed this characteristic occasionally. 3. If you have observed this characteristic to a considerable degree. 4. If you have observed this characteristic almost all of time.

1. Displays a great deal of curiosity about many things in learning science; is constantly asking questions about anything and everything in learning science

2. Generating a large number of ideas or solutions to scientific problems and questions; often unusual, unique, clever responses to scientific problems

3. Is uninhibited in expressions of opinion in learning science; is sometimes radical and spirited in disagreement; is tenacious

4. Is a high risk taker; is adventurous and speculative in learning science and facing some scientific problems

5. Displays a good deal of intellectual playfulness in learning science; fantasizes; images "wonder what would happen if …"; is often concerned with adapting, improving, and modifying institutions, objects, and systems in learning science

6. Displays a keen sense of humor in learning science or facing scientific problems and sees humor in situations that may not appear to be humorous to others

7. Is unusually aware of his impulses and more open to the irrational in himself in learning science; shows emotional sensitivity to scientific problems

8. Is sensitive to beauty in learning science; attends to aesthetic characteristics of science

9. Is nonconforming; accepts disorder; is not interested in details; is individualistic; does not fear being different in learning science and solving some scientific problems

10. Criticizes constructively; is unwilling to accept authoritarian pronouncements without critical examination in learning science knowledge

Appendix C

<u>Creative Activities and Accomplishments Check Lists</u>

This is an inventory, not a test. The inventory is simply a list of activities and accomplishments that are commonly considered to be creative. For each item, circle the answer (a) never (b) once or twice (c) 3-5 times (d) 5 –10 (e) more than 10 times that best describes the frequency of the behavior in question.

1. Won an award for a scientific project or paper
2. Had a scientific paper published
3. Invented a patentable device
4. Received a research grant or National Science Foundation Fellowship
5. Members of the Olympia camp training in science domain
6. Designed a scientific experiment on my own
7. Constructed something that required scientific knowledge, such as a radio, telescope, or other scientific apparatus on my own (not as part of a course)
8. Dissected a plant on my own
9. Dissected an animal on my own
10. Entered a project or paper into a scientific contest of any kind
11. Had a scientific project publicly displayed or exhibited
12. Participated in scientific research or project
13. Appointed as a laboratory assistant or teaching assistant in scientific field
14. Attended a summer science program
15. Participated in a scientific club or organization
16. To be a chief in a scientific club and also prepare teaching materials for other students
17. Read science books and journals on my own (not assigned reading)

Appendix D

Nature of Scientific Knowledge Scale (NSKS)

We would like to know your opinions about the nature of science. There are no right or wrong answers. Each of the statements describes a view about scientific knowledge. You may agree with some of the statements; you may disagree with other statements; or your feelings about statements may be neutral. After you have carefully read a statement, please tell us whether you strongly agree, agree, neutral, disagree or strongly disagree with it.

1. Scientific laws, theories, and concepts are stated as simply as possible.
2. The applications of scientific knowledge can be judged good or bad; but the knowledge itself cannot.
3. A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.
4. To build as great a number of laws, theories, and concepts as possible is the goal of science.
5. We accept scientific knowledge even though it may contain error.
6. Scientific knowledge expresses the creativity of scientists.
7. Moral judgment can be passed on scientific knowledge.
8. The laws, theories, and concepts of biology, chemistry, and physics are not related.
9. Scientific knowledge need not be capable of experimental test.
10. Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence.
11. Scientific laws, theories, and concepts represent imaginative thought.

12. It is meaningful to pass moral judgment on both the applications of scientific knowledge and the knowledge itself.
13. Scientific knowledge is not a product of human imagination.
14. Scientific knowledge is specific as opposed to comprehensive.
15. Relationships among the laws, theories, and concepts of science do not contribute to the explanatory and predictive power of science.
16. The evidence for scientific knowledge need not be open to public examination.
17. The truth of scientific knowledge is beyond doubt.
18. Even if the applications of a scientific theory are judged to be bad, we should not judge the theory itself.
19. A scientific theory is similar to a work of art in that they both express creativity.
20. There is an effort in science to keep the number of laws, theories, and concepts at a minimum.
21. The various sciences contribute to a single organized body of knowledge.
22. We do not accept a piece of scientific knowledge unless it is free of error.
23. The evidence for a piece of scientific knowledge does not have to be repeatable.
24. Discovering new scientific laws, theories, and concepts does not require creative thought.
25. Science aims at comprehensiveness and simplifications.
26. Certain pieces of scientific knowledge are good and others are bad.
27. Scientific knowledge is unchanging.
28. There are similarities among biology, chemistry, and physics.
29. Scientific laws, theories, and concepts are tested against reliable observations.

30. If two scientific theories explain a scientist's observations equally well, the more complex theory is chosen.
31. Scientific theories are discovered, not created by man.
32. Those scientific beliefs which were accepted in the past and since have been discarded, should be judged in their historical context.
33. Biology, chemistry, and physics are different kinds of knowledge.
34. It is incorrect to judge a piece of scientific knowledge as being good or bad.
35. Consistency among test results is a requirement for the acceptance of scientific knowledge.
36. The laws, theories, and concepts of biology, chemistry, and physics are interwoven.

Appendix E

Science Attitude Inventory (SAI II)

We would like to know your attitudes toward science. After you have carefully read a statement, decide whether or not you agree with it. If you agree, decide whether you agree mildly or strongly. If you disagree, decide whether you disagree mildly or strongly. You may decide that you are uncertain or cannot decide.

1. I would enjoy studying science.
2. Anything we need to know can be found out through science.
3. It is useless to listen to a new idea unless everybody agrees with it.
4. Scientists are always interested in better explanations of things.
5. If one scientist says an idea is true, all other scientists will believe it.
6. Only highly trained scientists can understand science.
7. We can always get answers to our questions by asking a scientist.
8. Most people are not able to understand science.
9. A major purpose of science is to enhance the development of technology.
10. Scientists cannot always find the answers to their questions.
11. When scientists have a good explanation, they do not try to make it better.
12. Most people can understand science.
13. The search for scientific knowledge would be boring.
14. Scientific work would be too hard for me.
15. Scientists discover laws which tell us exactly what is going on in nature.
16. Scientific ideas can be changed.
17. Scientific questions are answered by observing things.
18. Good scientists are willing to change their ideas.

19. Some questions cannot be answered by science.
20. A scientist must have a good imagination to create new ideas.
21. Ideas are the most important result of science.
22. I do not want to be a scientist.
23. People must understand science because it affects their lives.
24. A major purpose of science is to produce new drugs and save lives.
25. Scientists must report exactly what they observe.
26. If a scientist cannot answer a question, another scientist can.
27. I would like to work with other scientists to solve scientific problems.
28. Science tries to explain how things happen.
29. Every citizen should understand science.
30. I may not make great discoveries, but working in science would be fun.
31. A major purpose of science is to help people live better.
32. Scientists should not criticize each other's work.
33. The senses are one of the most important tools a scientist has.
34. Scientists believe that nothing is known to be true for sure.
35. Scientific laws have been proven beyond all possible doubt.
36. I would like to be a scientist.
37. Scientists do not have enough time for their families or for fun.
38. Scientific work is useful only to scientists.
39. Scientists have to spend most of time on research and study.
40. Working in a science laboratory would be fun.
41. Does your family encourage you to learn science? How do they encourage you?

    ____

    ____

42. Do you like to read science books? What kind of science books or magazines do you like to read?

____

43. Do you have any role models in science domain? Please list some names of scientists you admire most and hope you will be a scientist like them someday.

44. What kind of vocation do you like most? What kind of vocation do your parents hope you will choose?

45. Do you like physics? How do you like physics?

46. Do you like chemistry? How do you like chemistry?

47. Do you like biology? How do you like biology?

Appendix F

Problem Finding (PF)

Part 1: Exploring the behaviors of worms ?

If you need to find research topics related to the behavior of worms, please write down all problems you want to explore as much as possible.

Topic 1:

Topic 2:

Topic 3:

Topic 4:

Topic 5:

Topic 6:

Topic 7:

Topic 8:

Part 2: Cloned humans ?

You are a molecular biologist, and you are assigned to study the research of cloned humans. What kind of topics do you want to explore ? Please write them down as much as possible.

Topic 1:

Topic 2:

Topic 3:

Topic 4:

Topic 5:

Topic 6:

Topic 7:

Topic 8:

Appendix G

Formulating Hypotheses (FH)

Part 1: Poor Irish Elks ?

The Irish Elks have very huge antlers. Reliable estimates of their total span range up to 12 feet. Their antlers had been used as gateposts and temporary bridges. The Irish Elks evolved during the glacial period of the last few million years and survived to historical times in continental Europe, but they became extinct in Ireland about 11,000 years ago. Debates between scientists on the Irish Elks have been long centered on the reasons for their extinction. If you were a evolutionist, how would you explain the extinction of the Irish Elks ? (adapted from Gould, 1977)

Hypothesis 1:

Hypothesis 2:

Hypothesis 3:

Hypothesis 4:

Hypothesis 5:

Hypothesis 6:

Part 2: Mysterious Cicadas ?

The nymphs of periodical cicadas live underground for 17 years, sucking juices from the roots of forest trees. Then, within just a few weeks, millions of mature nymphs emerge from the ground, become adults, mate, lay their eggs, and die. Most remarkable is that three separate species of periodical cicadas in the same place follow precisely the same schedule, emerging together in strict synchrony (17 year life cycle). If you were a evolutionist, how would you explain such striking synchronization ? (adapted from Gould, 1977)

Hypothesis 1:

Hypothesis 2:

Hypothesis 3:

Hypothesis 4:

Hypothesis 5:

Hypothesis 6:

Hypothesis 7:

Hypothesis 8:

Appendix H

科學學習行爲互評表 (CRS)

這份問卷是有關於科學學習行爲的互評表。請仔細閱讀以下的行爲陳述，在**學習科學的情境**下，判斷你和你的同學是否**從未，偶爾，經常，總是**出現這樣的行爲，請在最適當的空格中打勾(√)。你的回答對你的同學並沒有任何的影響，不需要思考太久，只需要就你平常觀察到的行爲確實回答即可。對我來說，你們的回答是非常寶貴的資料，因爲由此將讓我對你和你們的同學有所了解，所以希望各位同學能認真的回答及思考問題。謝謝各位同學!

	從未	偶爾	經常	總是
1. 在學習科學時，會對許多科學的事物充滿好奇，並且會對許多的科學知識內容提出疑問。	□	□	□	□
2. 在面對科學問題時，會產生很多的想法或解答，而這些想法經常是很獨特、很聰明、且不同於一般的解答。	□	□	□	□
3. 在學習科學時，會毫無限制的表達自己的想法，有時會相當激烈且執著的表達對一些科學知識的不同意。	□	□	□	□
4. 在學習科學或面對科學問題時，非常具有探險精神和喜好思辨的。	□	□	□	□
5. 在學習科學時，經常是充滿想像力的，例如常想像“假如 ------，會發生什麼事”。	□	□	□	□

	從未	偶爾	經常	總是
6. 在學習科學或面對科學問題時，會展現敏銳的幽默感或意識到一些其他人所無法感受到的幽默。	□	□	□	□
7. 在學習科學時，能容忍一些不合理的事件和想法。	□	□	□	□
8. 在學習科學時，會對美的事物很敏感，能將科學和美學做聯結。	□	□	□	□
9. 在學習科學和解決科學問題時，對太細節的科學知識沒興趣，喜歡自我學習且不會害怕與人不同。	□	□	□	□
10. 在學習科學時，會提出具建設性的批評，不喜歡接受沒經過審慎批判就專斷地告知的知識。	□	□	□	□

Appendix I

<u>參予相關的科學活動與成果 (CAACL)</u>

這份問卷的主要目的是希望了解你們參予相關的科學活動與成果的情形。請仔細閱讀以下的問題，請在最適當的空格中打勾(√)。對我來說，你們的回答是非常寶貴的資料，所以希望各位同學能認真的回答問題。謝謝各位同學!

		0 次	**1**｜**2** 次	**3**｜**5** 次	**5**｜**10** 次	**10** 次以上
1.	我的科學作品或文章曾贏過獎。	☐	☐	☐	☐	☐
2.	我寫的科學文章曾被公開發表過。	☐	☐	☐	☐	☐
3.	我曾發明過一個有專利的裝置。	☐	☐	☐	☐	☐
4.	我曾收到科學相關的研究獎學金或國科會的研究補助。	☐	☐	☐	☐	☐
5.	我曾參加過奧林匹亞的集訓營。	☐	☐	☐	☐	☐
6.	我曾自己獨立設計科學實驗。	☐	☐	☐	☐	☐
7.	我自己會獨立做一些需要科學知識的東西，像: 收音機、望遠鏡或其他科學的儀器裝置 (非學校課程的一部份) 。	☐	☐	☐	☐	☐
8.	我曾經自己獨立解剖過植物。	☐	☐	☐	☐	☐
9.	我曾經自己獨立解剖過動物。	☐	☐	☐	☐	☐

		0次	1–2次	3–5次	5–10次	10次以上
10.	我的科學計劃或文章曾參加過科學競賽。	□	□	□	□	□
11.	我的科學計劃曾被公開展示過。	□	□	□	□	□
12.	我曾參加過科學研究或計劃。	□	□	□	□	□
13.	我曾被指定爲科學學科的小老師。	□	□	□	□	□
14.	我曾參加過暑期的科學營或由各大學所辦理的科學營隊。	□	□	□	□	□
15.	我曾參加過科學的社團或組織。	□	□	□	□	□
16.	我曾擔任科學社團或組織的組長，自己準備教材教授其他組員或學弟妹。	□	□	□	□	□
17.	我常閱讀科學相關的書籍或期刊 (非學校作業) 。	□	□	□	□	□

Appendix J

科學本質問卷 (NSKS)

這份問卷的主要目的是希望了解你們對科學本質的一些看法。你的回答並沒有好壞對錯的區別，不需要思考太久，只要以你個人的實際想法來作答即可。以下的每一個旭分別描述了一個對科學知識的觀點，請仔細閱讀以下的問題，看你是否**非常同意，同意，沒意見，不同意，非常不同意**這些陳述，請在最適當的空格中打勾(√)。對我來說，你們的回答是非常寶貴的資料，所以希望各位同學能認真的回答問題，謝謝各位同學!

	非常同意	同意	沒意見	不同意	非常不同意
1. 科學知識的陳述要盡可能的簡單。	□	□	□	□	□
2. 科學知識在它實際的應用上會有好壞之分；但科學知識的本身卻不能做如此的區分。	□	□	□	□	□
3. 在類似的條件下，如果其他研究者也能得到支持一科學知識的相關證據，則此科學知識將會被接受。	□	□	□	□	□
4. 科學的目標是盡可能增設更多的科學定律、理論和概念。	□	□	□	□	□
5. 我們接受科學知識，即使它可能含有錯誤。	□	□	□	□	□
6. 科學知識是科學家們創造力的表現和創作的成果。	□	□	□	□	□
7. 道德判斷可被加諸於科學知識上。	□	□	□	□	□
8. 生物、化學及物理上的定律、理論和概念是互不相關的。	□	□	□	□	□
9. 科學知識是不需要能被實驗所測試驗證的。	□	□	□	□	□
10. 今日的科學定律、理論和概念可能隨著新證據的出現而必須作改變。	□	□	□	□	□

	非常同意	同意	沒意見	不同意	非常不同意
11. 科學定律、理論和概念顯示了人類想像力的思考。	□	□	□	□	□
12. 對科學知識本身及科學知識的實際應用做道德上的評斷是有意義的。	□	□	□	□	□
13. 科學知識並不是人類想像力的產物。	□	□	□	□	□
14. 科學知識的適用範圍侷限於特定現象，而非涵蓋廣泛的。	□	□	□	□	□
15. 科學定律、理論和概念之間的相互關係，對科學的解釋和預測能力並沒有什麼貢獻。	□	□	□	□	□
16. 科學知識的證據並不需要公開讓大眾檢驗。	□	□	□	□	□
17. 科學知識的真確性是不容懷疑的。	□	□	□	□	□
18. 即使一科學理論在實際應用上獲得負面的評價，我們也不應該評斷此一科學理論本身的價值。	□	□	□	□	□
19. 科學理論和藝術品一樣，兩者都表達了人類的創造力。	□	□	□	□	□
20. 科學界致力於將科學定律、理論和概念的數目減至最少。	□	□	□	□	□
21. 各類不同的科學學科共同組成了一套有組織的知識體系。	□	□	□	□	□
22. 我們不接受任何的科學知識，除非它們正確無誤。	□	□	□	□	□
23. 科學知識的實驗證據不必能被重複。	□	□	□	□	□
24. 發現新的科學定律、理論和概念並不需要創造性的思考。	□	□	□	□	□
25. 科學目標在於知識的廣泛應用而非專一性的應用。	□	□	□	□	□

	非常同意	同意	沒意見	不同意	非常不同意
26. 有些特定的科學知識是好的，有些則是不好的。	□	□	□	□	□
27. 科學知識是不會改變的。	□	□	□	□	□
28. 有一些相似之處介於生物、化學與物理之間。	□	□	□	□	□
29. 科學定律、理論和概念依賴著可靠的觀測結果來做檢驗。	□	□	□	□	□
30. 如果兩個科學理論都同樣能解釋一個科學家的觀測結果，那麼較複雜的理論將會被選用。	□	□	□	□	□
31. 科學理論是被發現的，而非人類創造出來的。	□	□	□	□	□
32. 我們應該根據當時的歷史情境，去評斷那些現在已被淘汰而過去曾一度被我們接受的科學信念。	□	□	□	□	□
33. 生物、化學和物理是屬於不同種類的知識。	□	□	□	□	□
34. 評斷科學知識本身的好壞是不正確的。	□	□	□	□	□
35. 實驗測試結果彼此間的一致性，是科學知識被接受的必要條件。	□	□	□	□	□
36. 生物、化學和物理上的定律、理論和概念彼此間環環相扣。	□	□	□	□	□

Appendix K

科學態度問卷 (SAI II)

這份問卷的主要目的是希望了解你們對科學的態度。請仔細閱讀以下的問題，看你是否**非常同意，同意，沒意見，不同意，非常不同意**這些陳述，請在最適當的空格中打勾 (√)。你的回答並沒有好壞對錯的區別，不需要思考太久，只要以你個人的實際想法來作答即可。對我來說，你們的回答是非常寶貴的資料，所以希望各位同學能認真的回答問題， 謝謝各位同學!

	非常同意	同意	沒意見	不同意	非常不同意
1. 我喜歡學習科學。	☐	☐	☐	☐	☐
2. 任何我們所需要知道的事，都可以經由科學而找到解答。	☐	☐	☐	☐	☐
3. 去聆聽新的科學想法是沒用的，除非每一個人都同意它。	☐	☐	☐	☐	☐
4. 科學家們總是有興趣去尋找事物更好的解釋。	☐	☐	☐	☐	☐
5. 假如一個科學家說某一個理論或想法是真的，那麼其他的科學家將會相信它。	☐	☐	☐	☐	☐
6. 只有受過高度訓練的科學家們能夠了解科學。	☐	☐	☐	☐	☐
7. 總是能藉由請教科學家來獲得我們問題的答案。	☐	☐	☐	☐	☐
8. 大部分的人都不能了解科學。	☐	☐	☐	☐	☐
9. 科學主要的目的是要促進科技的發展，舉例來說電子學就是非常有價值的科學產物。	☐	☐	☐	☐	☐
10. 科學家們不可能總是找到他們想尋找的答案。	☐	☐	☐	☐	☐
11. 當科學家已經有一個很好的解釋時，他們不會試著去把它改的更好。	☐	☐	☐	☐	☐

	非常同意	同意	沒意見	不同意	非常不同意
12. 大部分的人都能夠了解科學。	□	□	□	□	□
13. 科學知識的追尋是相當無聊的。	□	□	□	□	□
14. 對我來說，科學研究太難了。	□	□	□	□	□
15. 科學家發現的定律，能真實確切的告訴我們在自然界中所發生的事情 。	□	□	□	□	□
16. 科學知識是可以改變的。	□	□	□	□	□
17. 科學的問題可以藉由觀察事物來回答。	□	□	□	□	□
18. 好的科學家將會願意去改變他們的想法。	□	□	□	□	□
19. 有一些問題，我們沒辦法藉由科學而找到答案。	□	□	□	□	□
20. 科學家必須有很好的想像力來創造出新的想法。	□	□	□	□	□
21. 想法就是科學最重要的產物。	□	□	□	□	□
22. 我並不想成爲一個科學家。	□	□	□	□	□
23. 人們必須了解科學因爲科學將會影響人類的生活。	□	□	□	□	□
24. 科學最主要的目的就是產生新的藥物和挽救生命。	□	□	□	□	□
25. 科學家必須誠實真確的呈現他們所觀察到的結果。	□	□	□	□	□
26. 假如一個科學家不能回答這個問題，那麼另一個科學家必定可以回答。	□	□	□	□	□
27. 我想要與其他的科學家一起做研究來解決科學的問題。	□	□	□	□	□
28. 科學試著去解釋自然界中事物變化是如何發生的。	□	□	□	□	□
29. 每一個市民都應該了解科學。	□	□	□	□	□

	非常同意	同意	沒意見	不同意	非常不同意
30. 我可能沒辦法做出很大的發明，但做科學相關的工作是蠻有趣的。	□	□	□	□	□
31. 科學主要的目的是幫助人類生活的更好。	□	□	□	□	□
32. 科學家不應該評價彼此的工作。	□	□	□	□	□
33. 領悟和判斷力是科學家必備的重要能力之一。	□	□	□	□	□
34. 科學家相信沒有任何一個科學知識能夠百分之百的被確定 是真實無誤的。	□	□	□	□	□
35. 科學定律是經過證明且不容懷疑的。	□	□	□	□	□
36. 我想要成爲一個科學家。	□	□	□	□	□
37. 科學家沒有足夠的時間和家人相聚或做一些有趣的事。	□	□	□	□	□
38. 科學工作僅對於科學家是有用的。	□	□	□	□	□
39. 科學家必須花大部分的時間做研究和研讀。	□	□	□	□	□
40. 在科學實驗室工作是有趣的。	□	□	□	□	□

41. 你的父母或兄姊是否有鼓勵你學科學？他們如何鼓勵或支持你？

____

____

42. 你喜歡閱讀科學相關的雜誌或書籍嗎？
請列出一些你喜歡閱讀的科學雜誌或書籍

____

____

43. 你是否有一些非常景仰或崇拜的科學家？請列出這些科學家的名字。

44. 你未來希望從事什麼樣的職業？你的父母希望你從事什麼樣的職業？

45. 你喜歡物理嗎？請寫出你如何的喜歡。

46. 你喜歡化學嗎？請寫出你如何的喜歡。

47. 你喜歡生物嗎？請寫出你如何的喜歡。

Appendix L

問題尋找 (PF)

Part 1: 探索蚯蚓的行爲？

假如你想要尋找一個與蚯蚓的行爲相關的研究主題，你可以得到所有你所需要的工具，請寫出你想要探索的問題？請盡可能的寫出你所想到的研究主題。

研究主題一：

研究主題二：

研究主題三：

研究主題四：

研究主題五：

研究主題六：

研究主題七：

研究主題八：

Part 2: 複製人？

試想你是一個分子生物學家，即將要做有關複製人的研究，你會想要探討哪些跟複製人有關的主題，你可以得到所有你所需要的工具，請寫出你想要探索的問題？請盡可能的寫出你所想到的研究主題。

研究主題一：

研究主題二：

研究主題三：

研究主題四：

研究主題五：

研究主題六：

研究主題七：

研究主題八：

Appendix M

形成假設 (FH)

Part 1: 可憐的愛爾蘭鹿？

愛爾蘭鹿的大角全長約 360 公分，鹿角大到可以用來搭在河上當作橋樑使用，這種愛爾蘭鹿的演化時期大約是在幾百萬年前的冰河期間，一直到歐陸人類出現時，仍然有愛爾蘭鹿的蹤跡，不過愛爾蘭鹿在距今一萬一千年左右全數滅絕。長久以來，科學家演化理論的辯論，總是集中在愛爾蘭鹿絕種的原因上，如果你是一個古生物學家，你會如何解釋這個愛爾蘭鹿滅絕的事件？請盡可能的寫出你所想到的假設。(adapted from Gould, 1977)

假設一：

假設二：

假設三：

假設四：

假設五：

假設六：

假設七：

假設八：

Part 2: 神奇的十七年蟬？

十七年的蟬，意味著生命週期爲十七年，這些蟬的幼蟲長期的住在地底下，整整十七年的時間，僅靠著吸吮大樹根的汁液過活。美國東部有三種不同種類的蟬，都遵循著十七年的週期，雖然居住在不同地方的十七年蟬會有不同的生活步調，例如：芝加哥地區和新英格蘭的蟬，各有各的「出土」年限，但只要生活在同一地點的蟬，不管種類一不一樣，它們總是同年同時出現。如果你是一個演化生物學家，你會如何解釋這樣一個漫長且精確一致的十七年蟬的生命週期？請盡可能的寫出你所想到的假設。(adapted from Gould, 1977)

假設一：

假設二：

假設三：

假設四：

假設五：

假設六：

假設七：

假設八：

Appendix N

Calculation of the Total Scores of Scientific Creativity, Problem Finding and Formulating Hypotheses

	An example: student A
The score of the Creative Rating Scale	10
The score of the Creative Activities Check Lists	6
The total score of scientific creativity	10 x 6 = 60
The score of levels of problem finding	Proposed 6 problems 1+2+2+3+1+2 = 11 cumulative percentiles: 68 %
The score of degrees of problem finding	Proposed 6 problems 6+2+2+4+1+1 = 16 cumulative percentiles: 74 %
The total score of problem finding	(68 % + 74 %) / 2 = 71 % ➔ 71
The score of levels of formulating hypotheses	Proposed 5 hypotheses 2+3+1+1+1+ = 8 cumulative percentiles: 43 %
The score of degrees of formulating hypotheses	Proposed 5 hypotheses 5+7+2+1+1 = 16 cumulative percentiles: 69 %
The total score of formulating hypotheses	(43 % + 69 %) / 2 = 56 % ➔ 56

Appendix O

Role Models and Parents' Expectations of Students with a Higher Degree of Scientific Creativity

	Do you have any role models in science domain?	Parents’ expectations about your careers?
1	No	Doctor, Businessman, Lawyer
2	Some famous geologists in Taiwan	Whatever I want
3	Einstein	Doctor, Researcher
4	Newton, Einstein, Edison	Whatever I want
5	Einstein, Lavoisier, Newton	Teacher
6	No	Whatever I want
7	Edison, Copernicus, Newton	Whatever I want
8	Einstein, Edison, Hawking	Whatever I want
9	Einstein, Feynman	Businessman
10	No	No
11	Faraday, Curie, Newton	Whatever I want
12	Nobel, Newton, Edison	Any career related to science

Appendix P

Role Models and Parents' Expectations of Students with a Lower Degree of Scientific Creativity

	Do you have any role models in science domain?	Parents’ expectations about your careers?
1	No	No
2	Einstein	Whatever I want
3	No	Any but can make a lot of money
4	No	No
5	No	Doctor
6	Einstein	Unknown
7	Einstein	Whatever I want
8	No	Whatever I want
9	Newton, Edison	Government Employees, Doctor
10	Edison	Unknown
11	Galileo	Unknown
12	Edison, Newton, Einstein	Whatever I want

BIBLIOGRAPHY

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education*, 76, 477-491.

Alfke, D. (1974). Asking operational questions. *Science and Children*, 11, 18-19.

Allison, A. W., & Shrigley, R. L. (1986). Teaching children to ask operational questions in science. *Science Education*, 70(1) 73-80.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching*, 34, 39-55.

Amabile, T. M. (1983). The social psychology of creativity. New York: Springer-Verlag.

Amabile, T. M., Hill, K. G., Hennessey, B. A., & Tighe, E. (1994). The work preference inventory: assessing intrinsic and extrinsic motivational orientations. *Journal of Personality and Social Psychology*, 66, 950-967.

Arlin, P. K. (1975). Cognitive development in adulthood: A fifth stage? *Developmental Psychology,* 11(5), 602-606.

Ashman, S. S., & Vukelich, C. (1983). The effects of different types of nomination forms on teachers' identification of gifted children. *Psychology in the Schools*, 20, 518-527.

Baer, J. (1993). Creativity and divergent thinking: a task-specific approach. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Baker, D. R. (1985). Predictive value of attitude, cognitive ability, and personality to science achievement in the middle school. *Journal of Research in Science Teaching*, 22(2), 103-113.

Besemer, S., & O'Quinn, K. (1986). Analyzing creative products: refinement and test of a judging instrument. *Journal of Creative Behavior*, 20, 115-126.

Besemer, S., & Treffinger, D. J. (1981). Analysis of creative products: review and synthesis. *Journal of Creative Behavior*, 15, 158-178.

Bloom, B. S. (1985). Developing talent in young people. New York: Ballantine.

Bloom, B. S., & Sosniak, L. A. (1981). Talent development. *Educational Leadership*, 39(2), 86-94.

Boden, M. A. (1994). Dimensions of creativity. Cambridge, MA: MIT Press.

Bruner, J. S. (1966). Toward a theory of instruction. Cambridge, Mass.: Harvard University Press.

Clarke, C. O. (1972). A determination of commonalities of science interests held by intermediate grade children in inner-city, suburban and rural schools. *Science Education*, 56, 125-136.

Collons, M. A., & Amabile, T. M. (1999). Motivation and creativity, In R. J. Sternberg (ed.), Handbook of creativity (pp.297-312). New York, NY: Cambridge University Press.

Cooley, W. W., & Klopfer, L. E. (1961). Test on understanding science. Princeton, NJ: Educational Testing Service.

Cropley, A. J. (2001). Creativity in education and learning: a guide for teachers and educators. Sterling, VA: Stylus Publishing.

Coxhead, P., & Whitefield, R. (1975). Science understanding measure test manual, University of Aston, Birmingham.

Cropley, A. J. (1972). A five-year longitudinal study of the validity of creativity tests. *Developmental Psychology*, 6, 119-124.

Cuccio-Schirripa, S., & Steiner, H. E. (2000) Enhancement and analysis of science question level for middle school students. *Journal of Research in Science Teaching*, 37(2), 210-224.

Darley, J. M., Glucksberg, S., & Kinchla, R. A. (1986). Pshchology (3rd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Davis, G. A. (1971). Instruments useful in studying creative behavior and creative talents: Part II. *Journal of Creative Behavior*, 5, 162-165.

Davis, G. A. (1975). In frumious pursuit of the creative person. *Journal of Creative Behavior*, 9, 75-87.

Davis, G. A. (1989). Testing for creative potential. *Contemporary Educational Psychology*, 14, 257-274.

Davis, G. A. (1997). Identifying creative students and measuring creativity. In N. Colangelo, & G. A. Davis (eds.), Handbook of gifted education (second edition) (pp.245-266). Needham Heights, MA: A Viacom Company.

Davis G. A., & Rimm, S. (1982). Group inventory for finding interests (GIFFI) I and II: Instruments for identifying creative potential in the junior and senior high school. *Journal of Creative Behavior*, 16, 50-57.

Dillon, J. T. (1982). Problem finding and solving. *Journal of Creative Behavior*, 16, 97-111.

Dori, Y. J., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: analysis of an environmental case study. *Journal of Research in Science Teaching*, 36(4), 411-430.

Driver, R., Leach, J., Miller, A., & Scott, P. (1996). Young peoples images of science. Bristol, Pennsylvania: Open University Press.

Duke, F. R. (1972). Creativity in science. *Journal of Chemical Education*, 49(6), 382-384.

Eichenberger, R. J. (1978). Creativity measurement through use of judgment criteria in physics. *Educational and Psychological Measurement*, 38, 221-227.

Einstein, A., & Infeld, L. (1938). The evolution of physics. New York: Simon & Schuster.

Endler, N. S. (1987). The scholarly impact of psychologists. In D. N. Jackson, & J. P. Rushton (eds.), Scientific excellence: Origins and assessment (pp.165-191). Newbury Park, CA: Sage.

Feldman, D. H., & Piirto, J. (1994). Parenting talented children. In M. Bronstien (ed.), Handbook of parenting (pp. 285-304). Mahwah, NJ: Erlbaum.

Finke, R. A. (1990). Creative imagery: discoveries and inventions in visualization. Hillsdale, NJ: Erlbaum.

Frederiksen N., Evans, F., & Ward, W. C. (1975). Development of provisional criteria for the study of scientific creativity. *The Gifted Child Quarterly*, 19(1), 60-65.

Fredericksen, N. (1984). Implications of cognitive theory for instruction in problem solving. *Review of Educational Research*, 54, 363-407.

Gardner, H. (1983). Frames of mind: the theory of multiple intelligencse. New York: Basic Books.

Getzels, J. W. (1975). Problem finding and the inventiveness of solutions. *Journal of Creative Behavior*, 9(1), 13-18.

Getzels, J. W., & Csikszentimihalyi, M. (1967). Scientific creativity. *Science Journal*, 3, 80-84.

Getzels, J. W., & Csikszentimihalyi, M. (1971). Discovery-oriented behavior and the originality of creative products: A study with artists. *Journal of Personality and Social Psychology*, 19(1), 47-52.

Getzels, J. W., & Csikszentimihalyi, M. (1976). The creative vision: A longitudinal study of problem finding in art. New York: Wiley.

Getzels, J. W., & Jackson, P. W. (1962). Creativity and intelligence: explorations with gifted students. New York: Wiley.

Gould, S. J. (1977). Ever since Darwin: reflections in natural history. USA: The American Museum of Natural History.

Guilford, J. P. (1967). The nature of human intelligence. New York: McGraw-Hill.

Haier, R. J., Siegel, B., Tang, C., Abel, L., & Buchsbaum, M. S. (1992). Intelligence and changes in regional cerebral glucose metabolic rate following learning. *Intelligence*, 16, 415-426.

Haladyna, T., & Shaughnessy, J. (1982). Attitudes toward science: a quantitative synthesis. *Science Education*, 66(4), 547-563.

Heinrich, S. (1995). Scientific Creativity: A Short Overview. *Educational Psychology Review*, 7(3), 225-241.

Hennessey, B. A., & Amabile, T. M. (1988). The conditions of creativity. In R. J. Sternberg (ed.), The nature of creativity: contemporary psychological perspectives (pp.11-42). Cambridge, England: Cambridge University Press.

Hocevar, D. (1976). Dimensions of creativity. *Psychological Reports*, 39, 869-870.

Hocevar, D. (1980). Intelligence, divergent thinking, and creativity. *Intelligence*, 4, 25-40.

Hogan K. (2000) Exploring a process view of students' knowledge about the nature of science. *Science Education*, 84, 51-70.

Holland, J. L. (1961). Creative and academic performance among talented adolescents. *Journal of Educational Psychology*, 52, 136-147.

Holmes, F. L. (1985). Lavoisier and the chemistry of life: An exploration of scientific creativity. Madison, Wisconsin: The University of Wisconsin Press.

Hoover, S. M. (1992). Scientific problem finding in gifted fifth-grade students. *RoeperReview*, 16(3), 156-159.

Hoover, S. M., & Feldhusen, J. F. (1990). The scientific hypothesis formulation ability of gifted ninth-grade students. *Journal of Educational Psychology*, 82(4), 838-848.

Hoover S. M., & Feldhusen, J. F. (1994). Scientific problem solving and problem finding. In M. A. Runco (ed.), Problem finding, problem solving, and creativity (pp.201-221). Norwood, New Jersey: Ablex Publishing Corporation.

Hukens, A. A. (1963). A factorial investigation of measures of achievement of objectives in science teaching. Unpublished Doctoral dissertation, University of Alberta, Edmonton.

Jay, E. S. (1996). The nature of problem finding in students' scientific inquiry. Unpublished Doctoral dissertation, Harvard University.

Kay, S. (1994). From theory to practice: promoting problem-finding behavior in children. *Roeper Review*, 16(3), 195-197.

Kimball, M. E. (1967-1968). Understanding the nature of science: A comparison of scientists and science teachers. *Journal of Research in Science Teaching*, 5, 110-120.

Klahr, D. (2000). Exploring science: the cognition and development of discovery processes. Cambridge, Massachusetts: The MIT Press.

Lehrer, R., Schauble, L., & Petrosino, A. (2001). Reconsidering the role of experiment in science education. In K. Crowley, C. D. Schunn, & T. Okada (eds.), Designing for science: implications from everyday, classroom, and professional settings (pp.251-278). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331-359.

Lederman, N. G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education*, 74, 225-239.

Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing the nature of science: What is the nature of our assessments? *Science and Education*, 7, 595-615.

Mackay, L. D. (1971). Development of understanding about the nature of science. *Journal of Research in Science Teaching*, 8(1), 57-66.

Mackworth, N. H. (1965). Originality. *American Psychologist*, 20, 51-66.

Majumdar, S. K. (1975). A system approach to identification and nurture of scientific creativity. *Journal of Indian Education*, 1(2), 17-23.

Mansfield, R. S., & Busse, T. V. (1981). The psychology of creativity and discovery: scientists and their work. Chicago: Nelson-Hall Inc.

Martin, M. (1972). Concepts of science education: A philosophical analysis. Glenview: Scott Forsman.

Mattews, M. R. (1994). Science teaching: The role of history and philosophy of science. New York: Routledge.

McComas, W. F., Almazroa, H., & Clougii, M. P. (1998). The nature of science in science education. *Science & Education*, 7, 511-532.

McComas, W. F., & Olson, J. K. (1998). The nature of science in international science education standards documents. In W. F. McComas (ed.), The nature of science in scienc education: rationale and strategies (pp.41-52). Kluwer Academic Publishers.

Mednick, S. A (1962). The associative basis of the creative process. *Psychological Review*, 69, 220-232.

Mooney, R. L. (1963). A conceptual model for integrating four approaches to the identification of creative talent. In C. W. Taylor, & F. Barron (eds.), Scientific creativity: its recognition and development (pp.331-340). New York: Wiley.

Moore, M. T. (1994). The ecology of problem finding and teaching. In M. A. Runco (ed.), Problem finding, problem solving, and creativity (pp. 174-187). New Jersy: Ablex Publishing Corporation.

Moore, R. W., & Foy, R. L. H. (1997). The scientific inventory: a revision (SAI II). *Journal of Research in Science Teaching*, 34(4), 327-336.

Moore, R. W., & Sutman, F. X. (1970). The development, field test and validation of an inventory of scientific attitudes. *Journal of Research in Science Teaching*, 7, 85-94.

Moravcsik, M. J. (1981). Creativity in science education. *Science Education*, 65, 221-227.

Musil, M., & Ondrusek, D. (1982). Relationships between internal and external criterions of scientific creativity. *Studia Psychologica*, 24(1), 55-62.

National Research Council (1996). National science education standards. Washington, DC: National Academy Press.

Nersessian, N. J. (1993). How do scientists think? Capturing the dynamics of conceptual change in science. Cambridge, Mass: the MIT Press.

Okuda, S. M., Runco, M. A., & Berger, D. E. (1991). Creativity and the finding and solving of real-world problems. *Journal of Psychoeducational Assessment*, 9, 45-
53.

Parloff, M. B., Datta, L., Kleman, M., & Handlon, J. H. (1968). Personality characteristics which differentiate creative male adolescents and adults. *Journal of Personality*, 36, 528-552.

Pouler, C. A., & Wright, E. L. (1980). An analysis of the influence of reinforcement and knowledge of criteria on the ability of students to generate hypotheses. *Journal of Research in Science Teaching*, 17(1), 31-37.

Quinn, M. E. (1971). Evaluation of a method for teaching hypothesis formation to sixth graders. Unpublished Doctoral dissertation, University of Pennsylvania.

Rachelson, S. (1977). A question of balance: a wholistic view of scientific inquiry. *Science Education*, 61(1), 109-117.

Reiner, M. (1998). Thought experiments and collaborative learning in physics. *International Journal of Science Education*, 20, 1043-1058.

Renzulli, J. S. (1978). What makes giftedness? Reexamining a definition. *Phi Delta Kappan*, November, 180-184.

Renzulli, J. S. (1982). Dear Mr. and Mrs. Copernicus: we regret to inform you. *Gifted Child Quarterly*, 26, 11-14.

Renzulli, J. S. (1983, September/October). Rating the behavior characteristics of superior students. *G/C/T*, 30-35.

Richardson, E., & Stanhope, R. W. (1971). Why do some secondary school pupils find science hard? A study involving 1700 pupils in Form I – IV in 5 N.S.W. schools. *Australian Science Teachers' Journal*, 17(3), 66-74.

Roskos-Ewoldsen, B., Intons-Peterson, M. J., & Anderson, R. E. (1993). Imagery, creativity, and discovery: conclusions and implications. In B. Roskos-Ewoldsen, M. J. Intons-Peterson, & R. E. Anderson (eds.), Imagery, creativity, and discovery: a cognitive perspective. (pp.313-328). Amsterdam, Netherlands: Elsevier Science Publishers.

Ross, S. D. (1981). Philosophical mysteries. Albany: State University of New York Press.

Rostan, S. M. (1994). Problem finding, problem solving, and cognitive controls: an empirical investigation of creativity acclaimed productivity. *Creativity Research Journal*, 7(2), 97-110.

Roth, W. M., & Roychoudhury, A. (1994). Physics students' epistemologies and views about knowing and learning. *Journal of Research in Science Teaching*, 31, 5-30.

Rubba, P. A., & Anderson, O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education*, 62(4), 449-458.

Runco, M. A. (1987). The generality of creative performance in gifted and nongifted children. *Gifted Child Quarterly*, 31(3), 121-125.

Runco, M. A. (1989). The creativity of children's art. *Child Study Journal*, 19, 177-190.

Runco, M. A. (1993). Divergent thinking, creativity, and giftedness. *Gfted Child Quarterly*, 37(1), 16-22.

Runco M. A., Noble, E. P., & Luptak, Y. (1990). Agreement between mothers and sons on rating of creative activity. *Educational and Psychological Measurement*, 50, 673-680.

Runco, M. A., & Okuda, S. M. (1988). Problem discovery, divergent thinking, and the creative process. *Journal of Youth and Adolescence*, 17(3), 211-220.

Schibeci, R. A. (1984). Attitudes to science: an update. *Studies in Science Education*, 11, 26-59.

Siegler, R. S. (1994). Cognitive variability: a key to understanding cognitive development. Current directions in psychological science, 1-5.

Simonton, D. K. (1988). Scientific genius: a psychology of science. Cambridge, England: Cambridge University Press.

Simpson, R. D., & Troost, K. M. (1982). Influences on commitment to and learning of science among adolescent students. *Science Education*, 66(5), 763-781.

Snow, C. P. (1960). The search. New York: Signet.

Songer, N., & Linn, M. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, 28, 761-784.

Sorensen R. (1992). Thought experiments. New York: Oxford University Press.

Sternberg, R. J. (1982). Reasoning, problem-solving, and intelligence. In R. J. Sternberg (ed.), Handbook of human intelligence (pp.260-305). Cambridge, England: Cambridge University Press.

Sternberg, R. J., & Lubart, T. I. (1995). Defying the crowd: cultivating creativity in a culture of conformity. New York: Free Press.

Subotnik, R. F., & Steiner, C. L. (1994). Problem identification in academic research: a longitudinal case from a adolescence to early adulthood. In M. A. Runco (ed.), Problem finding, problem solving, and creativity. (pp.188-200). Norwood, New Jersey: Ablex Publishing Corporation.

Swatton, P. (1992). Children's language and assessing their skill in formulating testable hypotheses. *British educational Research Journal*, 18(1), 73-85.

Tang, P. C. (1986). On creativity and the structure of science, essays on creativity and science, Proceedings of the Creativity and Science Conference, 167-173.

Tardif, T. Z., & Sternberg, R. J. (1988). What do we know about creativity? In R. J. Sternberg (ed.), The nature of creativity: contemporary psychological perspectives (pp.429-440). Cambridge, England: Cambridge University Press.

Thagard, P. (1994). Mind, society, and the growth of knowledge. *Philosophy of Science*, 61, 629-645.

Taylor, I. A., & Sandler, B. J. (1972). Use of a creative product inventory for evaluating products of chemists. Proc. 80th Annu. Conv. Am. Psychol. Assoc. 7, 311-312.

Torrance, E. P. (1962). Torrance tests of creative thinking. Bensenville, IL: Science Research Associates.

Torrance, E. P. (1963). Explorations in creative thinking in the early school years: a progress report. In C. W. Taylor, & F. Barron (eds.). Scientific creativity: its recognition and development (pp.173-183). New York: John Wiley & Sons, Inc.

Torrance, E. P. (1977). Creativity in the classroom. Washington, DC: National Education Association.

Torrance, E. P. (1988). The nature of creativity as manifest in its testing. In R. J. Sternberg (ed.), The nature of creativity: contemporary psychological perspectives (pp.43-75). Cambridge, New York: Cambridge University Press.

Torrance, E. P. (1990). Torrance tests of creative thinking: Norms-technical manual. Figural (streamlined) forms A and B, Bensenville, IL: Scholastic Testing Service.

Torrance, E. P., & Wu. T. H. (1981). A comparative longitudinal study of the adult creative achievements of elementary school children identified as highly intelligent and as a highly creative. *Creative Child and Adult Quarterly*, 6, 71-76.

Treffinger, D. J. (1986). Research on creativity. *Gifted Child Quarterly*, 30, 15-19.

Treffinger, D. J., Isaksen, S. G., & Dorval, K. B. (1995). Creative problem solving: an introduction, Center for Creative Learning, Sarasota, FL.

Vernon, P. E. (1979). Intelligence: heredity and environment. San Francisco, CA: Freeman.

Vernon, P. E. (1987). Historical overview of research on scientific abilities. In D. N. Jackson, & J. P. Rushton (eds.), Scientific excellence: origins and assessment (pp.40-66). Newburry Park, California: SAGE Publications.

Vernon, P. E. (1989). The nature-nurture problem in creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (eds.), Handbook of creativity: perspectives on individual differences. (pp.93-110). New York, NY: Plenum Press.

Wallach, M. A., & Wing, C. (1969). The talented student. New York: Holt, Rinehart, and Winston.

Wallach, M. A., & Kogan, N. (1965). Models of thinking in young children. New York: Holt, Rinehart, & Winston.

Wandersee, J. (1986). Can the history of science help science educators anticipate students' misconceptions. *Journal of Research in Science Teaching*, 23, 581-597.

Ward, T. B., Smith, S. M., & Finke, R. A. (1999). Creative cognition. In R. J. Sternberg (ed.), Handbook of creativity (pp.189-211). New York, NY: Cambridge University Press.

Wakefield, J. F. (1991). The outlook of creativity tests. *The Journal of Creative Behavior*, 25(3), 184-193.

Washton, N. S. (1967). Teaching science creativity: a taxonomy of pupil questions. *Science Education*, 51(5), 428-431.

Weisberg, R. W. (1986). Creativity: genius and other myths. New York: W. H. Freeman.

Weisberg, R. W. (1999). Creativity and knowledge: a challenge to theories. In R. J. Sternberg (ed.), Handbook of creativity (pp.226-250). New York, NY: Cambridge University Press.

Williams, F. E. (1980). Creativity assessment packet (H. T. Lin & M. J. Wang, Chinese Trans. 1994.). Aurora, NY: D.O.K. Publishers.

Wynn, D. C., & Bledsoe, J. C. (1967). Factors related to gain and loss of scientific interests during high school. *Science Education*, 51, 67-74.

Yamamoto, K. (1963). Relationships between creative thinking abilities of teachers and achievement and adjustment of pupils. *The Journal of Experimental Education*, 32(1), 3-25.

Ypma, E. G. (1968). Prediction of the industrial creativity of research scientists from biographical information. Unpublished Doctoral dissertation, Purdue University.

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