

# INVESTIGATING CREATIVITY IN SCIENTISTS

by

NOPARAT SRICHAROEN

(Under the Direction of BONNIE CRAMOND)

## ABSTRACT

The study of investigating creativity in science contained two experimental studies. The main purposes of the studies were to develop a creativity test in a subject, chemistry, by using the Construct Map Method and use it to understand the profiles of creative students and scientists along with some other tests: the Torrance Tests of Creative Thinking Test: Verbal form (TTCT-V), the Gough Personality Scale, and the Activity Check List from Runco Creativity Assessment Battery (rCAB). The result from developing the Creativity Test in Chemistry (CTC) indicated that it measures two creative constructs: the qualities of fluency and association flexibility, with high reliability for the two constructs. All the items had acceptable weighted fit mean square values. In the second experiment, participants with high scores on the CTC tended to have high scores on the TTCT-V, according to the result of the cluster analysis. However, the low correlation between the two tests implied that even though the two tests claim to measure the same creative skills of fluency and flexibility, they did not measure the same things. The two-way ANOVA with levels of expertise and areas of science as independent variables and the scores on the CTC as the dependent variable also showed that participants in chemistry at all levels of expertise performed better than in other areas of science: physics and biology. In the chemistry major, the higher the level, the higher the scores earned. This indicated that both

content knowledge and creative thinking were necessary to do well on a task of creativity in a specific domain, suggesting the importance of integrating creative thinking skills and content to nurture creativity in a domain subject. For this group of participants, the Principal Component Analysis (PCA) of the Gough Scale suggested eight personality traits that they have in common: confidence, insight, sincerity, creativity, nonconformity, skepticism, humility, and narrow interests. There was no significant difference among activities related to science in which the three groups, high ability, competent ability, and low ability, were engaged. Since the participants in these groups were in science majors, their activity involvement might not have been different. However, there was a significant difference in a personality factor: skepticism between the competent and the low ability groups. This trait should be nurtured in scientifically gifted individuals.

INDEX WORDS: Creativity, Science and creativity, Chemistry and creativity, Torrance Tests of Creative Thinking, Verbal form (TTCT-V), Gough Personality Scale, Activity Check List of the Runco Creativity Assessment Battery (rCAB), Gifted personality, Scientifically creative personality, Construct Map

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NOPARAT SRICHAROEN

B.Ed. (Hons.), Chulalongkorn University, Thailand, 2003

M.Ed., Chulalongkorn University, Thailand, 2005

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NOPARAT SRICHAROEN

Major Professor:	Bonnie Cramond
Committee:	Mark Runco
	Martha Carr
	Tarek Grantham

Electronic Version Approved:

Suzanne Barbour  
Dean of the Graduate School  
The University of Georgia  
August 2016

## DEDICATION

I dedicated every benefit resulting in the growth of knowledge in gifted education from my work to my dearest mother, Sumnao Uamma.

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## CHAPTER 1

### INTRODUCTION AND LITERATURE REVIEW

It does not take much effort for us to name very creative individuals. Names such as Mozart, Shakespeare, and Einstein certainly pop up in our minds. Were they creative people, or were they a creative musician, writer, and physicist? In other words, was Mozart creative only in music, Shakespeare in writing, and Einstein in physics?

The discussion of general or specific creativity is analogous to the discussion of general or specific intelligence. The idea of general intelligence, or “g,” a global mental ability, versus domain-specific intelligence is one of the most debated issues in psychology (Gottfredson, 2003a). The generality of intelligence refers to the idea that people who are intelligent in one mental aptitude tend to be intelligent in all. One extreme idea holds that “g” is fixed, and there cannot be a significant development of intellectual ability for an individual. In other words, if you do not have a lot of “g” when you enter kindergarten, you are never going to have a lot of it (Murray, 2007).

Gottfredson (1997) also defined “g” as a highly general ability for processing complex information of any kind. She reviewed several studies that show the predictive validity of “g” on job performance. In one conclusion, when academic knowledge is not required in jobs, higher “g” increases high performance. Gottfredson, Finucci, and Childs (1984) also concluded that a group of dyslexic men is able to perform at high-level jobs in which academic credentials are not required. Professionals rated academic credentials, reading, and writing to be more important, whereas salesmen who were high-level executives highly rated nonacademic competencies such

as taking initiative, and being responsible and persuasive. Their results supported the evidence of how “g” fitted with particular groups in order to effectively develop it in such groups.

Ceci (1991) reviewed the importance of schooling for IQ and summarized that schooling fosters the development of cognitive processes and that students can improve their IQ results through practices. Such practices do not depend on the variation in the quality of school—that is, IQ tests can be properly used as a screening and prediction tool of academic success. In other word, as IQ scores can be strengthened through school practice, IQ tests can serve as a formative assessment to successfully develop students’ cognitive skills.

However, some psychologists oppose the fixed view of generality in intelligence. Instead, they believe that developing intelligence required in domain subjects helps people achieve at an exceptional level in such particular domains. Schneider (1993) held the opinion that specific educational experiences and intensive as well as extensive domain-specific training and practice determine the acquisition of a skill. Deliberate practice allows individuals to acquire qualitatively different mental representations. The increasingly complex mental representations also help individuals bypass the information processing constraints imposed by their working memory capacities, and thus they master the skills in a specific domain. Ericsson (2003) also stated that continued deliberate practice is important for individuals to reach and maintain their high levels of professional performance. He pointed out the differences between acquiring everyday skills and professional skills in the acquisition of an expert status. Acquiring everyday skills occurred rapidly, while professional development required years or even decades of experience.

Sternberg (1985) characterized experts in a given domain as those who have a great deal of knowledge or rich schema in a domain, have well-organized and interconnected knowledge stored in their memory, spend time pondering a solution before implementing it, work forward

from a given problem to develop a solution, possess good evaluation in choosing the best solution, store procedural knowledge and are capable of retrieving it when necessary, have automatization of skills or steps required to tackle a problem, have high problem-solving ability, have accurate prediction about task difficulty, are able to monitor their own problem-solving strategies and processes, and demonstrate a high accuracy rate in producing solutions to problems.

Clark (2008) presented learning events proven to build expertise, namely, supporting the transfer of learning, building new mental models, managing attention, and optimizing the working memory. This will help facilitate the development of expertise in a variety of domains, such as sports, medicine, programming, music, and chess. An expertise that is domain specific requires extensive and deliberate practice, different viewpoints delineated from others, and two forms of intelligence: routine and adaptive expertise. Yet, experts could face mental fixedness. When problems are challenging, diverse expertise is required.

It is undeniable that some general intelligence skills are required for academic or job success. However, general intelligence skills are mostly viewed as practical intelligence in everyday life. The vague definition of what skills are considered “g” and how applicable they can be implemented in schooling practices still present a challenge. Defining such skills to be fostered in the school setting is important. It may not be practical to teach such skills without the promotion of knowledge, especially if IQ can be developed through school practices (Ceci, 1991). An expert’s view on intelligence clearly defines deliberate practices as an important tool to help individuals reach an elite level in a domain.

There are studies of experts’ views on developing intelligence in a domain. Patel and Groen (1986), for example, investigated seven cardiologists’ reasoning about a case of bacterial

endocarditis. The cardiologists were tested individually and allowed 2.5 minutes to read the case description. Then, they had to write down as much as of the text they remembered, describe the underlying pathophysiology, and then provide a diagnosis. All the processes used a writing format. Then, the cardiologists' responses were coded to elicit their reasoning. The study showed that the expert cardiologists who gave an accurate diagnosis used pure forward reasoning through a network of causal rules. These rules were based on the physicians' underlying knowledge rather than on the case description in the text. On the other hand, the subjects with inaccurate diagnoses were inclined to use a mixture of forward and backward reasoning, start with a high hypothesis and use the top-down fashion to make a comparison with the given case to diagnose, or generate irrelevant rules. To wrap up, physicians who made accurate diagnoses possessed more expertise.

Santos and Gerling (2012) studied how 15 college and postgraduate students approached a new piece of music. The students had to study *Ponteio* no. 22 by the Brazilian composer Guarnieri (1907–93) for 16 weeks without receiving guidance from their piano teachers. Their practice was monitored in four sessions. Their performance was recorded on a video- and audio-tape as well as on interviews. Based on the analysis, the students' practice or performance showed the ways of knowing from the matrix of cognition skills in music. A number of students could identify problems outside their own performance, and their cognitive skills highly depended on expertise level.

Ward, Hodges, Starkes, and Williams (2007) studied 203 male soccer players aged between 8 and 18 by using a participation history questionnaire. The findings revealed that the skill levels of the players could be obviously and consistently discriminated by week and accumulated by the hours spent in soccer team practice across ages. Exceptional players were

engaged in decision-making activities during team practice, had high levels of motivation, and received considerable parental support. However, players' time spent in playful activities or various sports did not differ between groups. Deliberately designed activities tended to improve performance, leading to an elite status rather than mere experience.

Expertise is viewed as domain specific intelligence. An elite performance in a specific domain of intelligence can be trained through deliberate practices. Ericson (2006) defined expertise as characteristics, skills, and knowledge that experts possess, which distinguishes them from novices or less experienced people. Ericson, Krampe, & Tesch-Romer (1993) stated that deliberate practice is specially designed to challenge individuals' performance to go beyond their current level of performance. A set of conditions required for improved performance includes a well-defined goal, motivation to improve, feedback, and opportunities for perfecting skills or knowledge. Accessing to coaches or instructors, training materials, and training facilities to maximize improvement of performance are also important parts of deliberate practice. To become experts, it is vital for people to engage in the deliberate practice of a particular domain of intelligence for a 10-year period.

In sum, different viewpoints held about the definition of intelligence can bring about different approaches to developing intelligence. If intelligence refers to general skills, such skills can be independently taught by ignoring knowledge and skills related to any academic subjects. However, if intelligence is viewed as the development of expertise in a domain, certain knowledge and skills related to the acquisition of high level of performance in such domain will be integrated into curriculum.

Since there is a debate about whether creativity is domain specific or general, the definition of creativity that is selected will bring about different interventions to support ones'

creative thinking as well. If a person believes that creativity is domain-general, creativity will be nurtured in general activities. For example, an ideation activity intended to enhance students' creativity can also be employed to develop students' divergent thinking skills in chemistry. On the other hand, if one regards creativity as domain specific, creativity will be fostered within a particular context or area of talent (Plucker, 1998).

Some researchers advocate that creativity is a generalized ability, an ability that is not tied to subject domains (Guilford, 1959; Hocevar, 1976; Milgram 1990; Plucker, 1998; Torrance, 1966). This is similar to the belief that there is a general intelligence factor, or G, independent of specific domain-relevant abilities (Gottfredson, 2003b).

A pioneer in creativity research, Guilford (1959) proposed that the structure of intellect can be conceptualized as a three-dimensional cube by which intellectual operations, contents, and products form each of the dimensions. According to this view, thinking processes, including creative thinking, are generalized abilities that might be applied to different categories of content in order to produce a variety of products.

Along the same line, Torrance conceptualized the construct of creativity with an attempt to measure and nurture students' creativity. Torrance's Tests of Creative Thinking (TTCT) are based on the premise of the generalization of creative thinking across domains, adopted from Guilford's structure of intellect. The purpose of the assessment is intended to measure creative thinking abilities, which refer to that constellation of generalized mental abilities that is commonly presumed to be brought into play in creative achievements (Torrance, 1990, 2008). The TTCT measures divergent thinking, and other creative processes, as a function of a person's creativity.

On the other hand, several psychologists believe that creativity is domain specific (Csikzentmihalyi, 1988; Baer, 1998). This is similar to the view that intelligence is domain specific, as promulgated by researchers such as Gardner (1993).

Gardner (1993) proposed the theory of multiple intelligences (MI) with the goal of expanding and reformulating our view of intelligence so that we will be able to devise more appropriate ways of assessing and nurturing it. He posited that there are seven distinct intelligences: linguistic, musical, logical-mathematical, spatial, bodily-kinetic, and interpersonal. This theory assumes that intelligence tests must be constructed to measure students' strengths within a domain of specificity. An MI perspective is intent on developing experts who attain a high level of achievement in a particular domain. There is a set of activities and operations required for successful endeavors in a domain. However, Gardner did not clarify a specific process that can help increase intellectual capacities within each domain of intelligence.

Similarly, Baer (1998) advocated the domain specificity of creativity, and domain specificity should include the variety and variation of task specificity. He conducted several studies to buttress his position. In one of his studies, he performed an experiment designed to investigate whether the creative process is domain general or specific (Baer, 1994). A group of students received divergent thinking training, and the others received training in solving mathematical word problems. The students in the two groups were given five tasks: telling stories, writing stories, writing poems, writing mathematical word problems, and making collages. Experts assessed the creativity of each product. As the correlations among the scores on the five tasks were low, Baer took that as evidence that there are several task-specific factors, rather than one general factor.

Some psychologists fall in between these two poles of the domain generalization and domain specification of creativity. From this school of thought, the creative process is applicable across domains, but expertise in a domain is vital to creative achievement in that domain. For example, Simonton (2007) postulated that content knowledge or expertise may provide cognitive capacities for individuals, while creative processes are relatively broad in application. The acquisition of certain knowledge and skills in a domain helps individuals solve problems that anyone who attains the same level of expertise can tackle. However, the creative processes of domain-free thinking in creativity allows experts to generate possibilities and perform tests based on their solid knowledge and skills in their domain of expertise to produce new and original products in their domain. From this, one could conclude that knowledge and general creativity go hand in hand to support individuals' creative productions.

Amabile (1983) defined creativity as a component of domain-relevant skills, creativity-related skills, and task motivation. The appropriate storage and use of domain-relevant information or skills are necessary for creative achievement. Creativity-related skills are important to solve any problems and can be taught implicitly or explicitly. Task motivation relies on attitudes toward the task and intrinsic motivation to help individuals to persist in achieving creative products. All three components and different levels of each component determine the level of creative achievement.

Kaufman and Baer (2005) proposed the amusement park theory of creativity to compromise on the debated issue of whether creative thinking is domain generalized or specific. They made an analogy of Disney World to elaborate on their theory, consisting of five main facets: initial requirements, general thematic areas, domains, specific tasks or microdomains, and strange connections (e.g., errors in the model). Initial requirements include things necessary for

any kind of creative production, namely intelligence, motivation, and environment. The initial requirements are requirements of the park, such as the height requirements, photo policies, or warning signs on the rides. General thematic areas are the four theme parks: the Magic Kingdom, Epcot, Disney-MGM studios, and the Animal Kingdom. Individuals decide to choose one general theme to enter, the same as individuals select a general field that contains underlying rules and concepts of several disciplines or domains under it. Within each of these general themes are several more narrowly defined creativity domains, like when an individual is at the Magic Kingdom, he or she can choose to go to Fantasyland, Adventureland, Liberty Square, Frontierland, Mickey's Toontown Fair, or Tomorrowland. If an individual is at Tomorrowland, there are still big differences between Space Mountain and Buzz Lightyear's Space Ranger Spin. This means, within a domain, there are several commonalities among all the specific tasks that are part of the domain. Lastly, there are connections between the general themes, domains, and specific tasks, the same as there are commonalities between the roller coasters in the park.

According to this view, the creative process allows resilience in thoughts, which enables experts to be capable of addressing and solving problems for which they have been trained. Therefore, the general creative process, along with solid knowledge and skills in a particular domain, should be bolstered to help students attain higher levels of achievement.

A summary of the points of view from different schools of thought about the construct of creativity, whether it is domain general or specific, is presented in Table 1.1. The table describes the strengths and weaknesses of each viewpoint. The view of creativity as domain general has the strength that creative thinking skills can be generally taught in any subject, but the transfer of the skills to solve problems in the subject is questionable. Whereas, if creativity is seen as domain specific, expertise contributing to creative achievement in a subject domain is fostered.

However, general creative processes or skills may be ignored, causing fixedness of thoughts due to a large amount of knowledge accumulated in the domain. To view creativity as both domain general and specific assures that the creative thinking skills and the content in domains will be embodied to nurture one's creativity. Defining all relevant components to support creativity in this school of thought is a challenging task.

Table 1.1

*Summary of Viewpoints, Strengths, and Weaknesses of Creativity*

<b>Creativity Viewpoints</b>	<b>Strengths</b>	<b>Weaknesses</b>
Creativity as domain general (Creativity is a generalized ability, an ability that is not tied to subject domains.)	Creative activities can be integrated in every curriculum to enhance students' creative thinking. Creative thinking skills can be transferred to every domain.	Creative skills that are tied to content may not be strengthened.
Creativity as domain specific (Creativity occurs as a result of training or expertise in a domain.)	Content and creativity in a domain are simultaneously fostered.	Rigidity in thoughts may prevent experts from developing original ideas.
Creativity as domain general and specific (Creativity is viewed as domain general because of its applicable process across domains but is considered domain specific as the result of expertise.)	Certain cognitive skills in a domain are strengthened, and transferable cognitive skills across domains also happen, which promote the depth and the breath of the applications of creative skills within and across domains.	Different sets of creativity should be implemented to develop creativity within a domain and across domains.

The theoretical viewpoint for these studies is that creativity should be viewed as both domain specific and general. Nurturing creativity in a domain will enable individuals to grasp the high level of content and skills to solve complex and difficult problems in a domain. However, helping individuals to transfer their expertise in a domain to solve new and challenging problems in real life situations or in different contexts through the use of the creative process, which is considered domain general, will help experts break mental fixedness and discover originality in unfamiliar tasks in which high levels of knowledge and skill in their domain expertise cannot be used to develop solutions.

Studies conducted to investigate the evidence of whether creativity is domain general or specific are still unclear. Correlations among diverse products that creative people have generated were used to indicate whether creativity is domain general or specific (Hocevar, 1976 & Bear, 1994). Hocevar (1976) concluded that correlations among different types of creative products suggested a general trait of creativity, while Bear (1994) summarized that low correlations among varying creative products produced by each participant showed that creativity is domain specific. Using such correlations to conclude the construct of creativity has a flaw, as creative people are not necessarily creative in every domain subject; there are skill, motivation, and knowledge differences.

To provide a better realization of this inconclusive issue, there is a need for further research to clarify this issue. An investigation of participants whose interests or majors are science will show whether there are differences in general creativity or creativity in a specific domain, which is chemistry, among participants in different majors: chemistry, biology, and physics and in different expertise levels: high school, university, and workplace. If creativity is domain general, there should be no difference between the tests results of general creativity and of creativity in chemistry among participants in the three majors, especially for those in chemistry. Within the same major, the lack of differences among participants across expertise levels for a general creativity test will provide strong evidence of creativity being a domain general, while differences in the creativity in a chemistry test may show a tendency for creativity to be a domain specific. Such possible findings will give educators more sophisticated insights about how to nurture creativity within and across domains as well as across levels of study.

## **Creative Personalities**

Characteristics of creative people are usually studied as traits across all domains or disciplines. Sternberg and Lubart (1992) averred that creative people share some attributes such as originality, open-mindedness, imagination, curiosity, high motivation, intuition, and a sense of humor. However, several studies have attempted to reveal creative characteristics in certain disciplines, such as the sciences, arts, and music. Feist (1998) did a meta-analysis to discover whether creative traits varied across disciplines. According to his study, creative individuals in the arts and sciences did not share creative personality traits completely. Creative artists tended to be more emotionally unstable, and displayed coldness and obnoxiousness more than creative scientists.

As a result, unique creative traits in particular disciplines should be further investigated to highlight the recognition and, in some cases, fostering of such traits in the disciplines. Feist (2006) stated that one problem with the research on personality and scientific interest or achievement was that it was not specific to any domain of science but rather covers scientists in general.

Although there are studies about the characteristics among scientists that were widely investigated between 1950-1960 with personality adjective checklists or inventories (Roe 1952; Van zelst & Kerr, 1954; Chamber, 1964; Albert & Runco, 1987; Shapiro, 1968), certain characteristics of scientists, especially scientists in physics, chemistry, and biology, have not been delineated. The lack of specific personality inventories unique to scientific disciplines may be a contributing factor to this problem. The employment of general personality tests, such as the 16 Personality Factor (16PF), the Activity Check List Questionnaire (ACL) or the Big Five Personality test (Big 5), has been popular in assessing the characteristics among creative

scientists. Such tests have an advantage in covering a wide range of personality traits, thus thoroughly capturing traits that may be unique for individuals not only in science, but also other fields. However, when the creative personality in scientists is studied, some distinct traits relevant to the creative achievement of scientists should be infused in those general personality tests. Such inclusion will provide more solid evidence about the importance of those distinctive traits in the development and/or fostering of creative personality traits in the different sciences. This study will explore the creative personalities of those with science majors/careers in physics, chemistry, and biology, which are rarely investigated and usually studied together with other branches of science. The findings may help strengthen our knowledge about creative personalities among scientists in these fields and especially in students as the three majors are the main subjects taught in school.

### **Creativity and Context**

Several psychologists have presented creativity as a result of the complexity of factors or components (Rhodes, 1961; Csikzentmihalyi, 1988, Amabile, 1990; Milgram, 1990; Runco & Chad, 1995). In helping develop one's creativity, the interaction among different factors, such as domains, environment, and society, should be taken into account. Rhodes (1961), Csikzentmihalyi (1988), and Milgram (1990) have provided very broad theories about factors contributing to creativity.

Rhodes (1961) proposed the four Ps of creativity: person, process, press, and products. The term *person* includes information about personality, intellect, temperament, physique, traits, habits, attitudes, self-concepts, value systems, defense mechanisms, and behavior. The term *process* refers to motivation, perception, learning, thinking, and communication. The creative process can be taught in an educational setting. *Press* involves the relationship between

individuals and their environment. Creative production is influenced by the context in which they grew up and function. The term *product* refers to any forms of tangible products that are transformed. Creative individuals use products to communicate their original ideas to audiences.

Csikzentmihalyi (1988) also presented a dynamic model of the creative process, which is composed of three main systems: person, field, and domain. The interplay among these three systems contributes to the creative process and the creative achievement. A person's creative process involves cognitive abilities and motivational and affective variables. The domain level indicates the information necessary in domains. The field is the effect of the social system on creativity.

Milgram (1990) defined creativity as a process of problem solving in which original products are generated. A product can be a response, idea, or solution. Originality means unusual (rare occurrence) and of high quality (i.e., productive, valuable, and worthwhile). He also developed a  $4 \times 4$  model of the structure of giftedness to characterize gifted and creative individuals. Based on his model, the four categories of giftedness are general intellectual ability or overall general intelligence, specific intellectual ability, general original/creative thinking, and specific creative talent. The three different levels at which individuals demonstrate creativity are mild, moderate, and profound. Creative performance is the result of a complex interaction of environmental contexts, such as school setting, family setting, and community setting with cognitive abilities and personal social characteristics.

Not only does creative achievement differ because of the interaction in domains, culture is also a vital contributing factor. Rudowicz and Ng (2003) argued that it is much harder for Asians to think, feel, and act in a creative manner than for Westerners thanks to the tightly organized, collectivistic, hierarchical, and face-conscious Asian society.

Some studies have investigated how different types of cultures influence creativity. Societies from tight and loose cultures have different propensities for producing creative work. Gelfand (2011) studied the differences between tight and loose cultures in 33 countries by using his own tightness-looseness scale. According to him, tight cultures pose strong social norms and have low tolerance for deviant behavior, while loose cultures have less strict social norms and high tolerance for deviant behavior. According to the results of his scale, Asian countries are more likely to be associated with tight cultures because of high scores on the scale. Countries with scores higher than 10 included India, Malaysia, Pakistan, Singapore, and South Korea. Countries determined to have loose cultures with scores of around 5 or lower were Australia, Brazil, Estonia, Israel, the Netherlands, and the United States.

Chua, Roth, and Lemoine (2015) also proposed that creativity involvement and success rely on cultural tightness. Countries with cultural tightness are those strongly influenced by social norms and less tolerant of deviant behaviors. Cultural tightness emerges differently. The innovator and the audience's receptivity to an innovative idea have influenced cultural tightness, the distance between these two factors was taken into account. By using a crowdsourcing platform to organize creative contests for consumer product brands and with the judgments of experts in marketing, the researchers found that individuals from tight cultures have a lesser tendency to engage and succeed in foreign creative tasks. This finding is intense if the cultural distance between the innovator and the audience increases. People from a tight culture have a poor recognition of foreign creative ideas. However, in a circumstance where an individual from a tight culture is able to produce a creative work, then that person has demonstrated a creative work in his or her own culturally close country.

As culture is an important factor of creativity, it is conceivable that the context of creativity among the Thai population should be studied. The results of such research will provide additional knowledge of creativity in terms of interactions in a domain and in cultures.

In order to provide empirical evidence that would support the nurturance of creativity within a domain, specifically chemistry, and the promotion of creative personalities, two research experiments will be conducted. The first research involves the development of a creativity test in a specific subject, which is chemistry. To develop creativity in chemistry, it is imperative that an assessment is able to reflect it. The result of the study will support the theoretical viewpoint underlined in the studies as mentioned earlier. Creativity should be viewed as domain general and specific. Creative thinking skills can be viewed as general to allow individuals to apply such skills to excel in a domain. The creativity test intends to measure both knowledge and chemistry in the first study and presents the possibility of an appropriate assessment advocating this standpoint. As creativity is a complex construct involving interactions among person, domain, and culture, the second study will be investigated on this issue. This study will give a better understanding of how this interaction contributes to creativity in a specific domain and context. The result will also be useful for the nurturance of creativity in a certain contextual environment.

### **Research Questions**

1. Can a creativity test in chemistry be developed according to the Construct Map approach that will show validity and reliability?
2. Will there be differences in creativity profiles among participants from three branches of science--physics, chemistry, and biology--at three levels-- high school, undergraduate, and

professional when scores from different creativity tests, personality measures, and engagement in science activities are studied?

## CHAPTER 2

DEVELOPING A CREATIVITY TEST IN CHEMISTRY BY USING A CONSTRUCT MAP<sup>1</sup>

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<sup>1</sup> Sricharoen, N. To be submitted to *Creativity Research Journal*.

### Abstract

The purpose of this study was to develop a Creativity Test in Chemistry (CTC) that would measure both creative thinking and knowledge in chemistry at the same time. Based on a Construct Map (Wilson, 2005), the six questions on the test measure two constructs of creativity, fluency and flexibility, as well as knowledge of chemistry. Between-item multidimensionality was selected to estimate participants' ability and item difficulty. The Delta Dimensional Alignment technique (DDA) was also used to allow comparisons across models. The results indicated that the CTC measured two constructs: the quality of fluency and the association flexibility as the two-dimensional model had a better fit than the unidimensional mode in which scores from fluency and flexibility were combined as one dimension indicated by significant  $\chi^2(2) = 9.0686$ , \*  $p < .05$  and smaller values in AIC, BIC, and  $G^2$ . There were high correlations ( $r = .99$ ) for the two dimensions. The test had high EAP reliability for the two dimensions, .815 and .816, respectively with the separation reliability 1.00 and Cronbach's Alpha .79. The mean estimates of difficulties in dimension 1 and 2 were low, -.019 and .027, respectively. All items had good fits as weighted fit mean square values fell into acceptable range. There were differences in mean performance when different genders, levels of study, and majors were considered. Overall, the results were encouraging to apply the construct map to evaluate both creativity and content mastery in a domain subject in a classroom setting.

**Keywords:** Creativity test in Chemistry, Construct Map, Creativity, Multidimensional Random Coefficients Multinomial Logit (MRCML), Differential Item Functioning (DIF), Expected A Priori (EAP) Estimation, Rasch Model

The definition of creativity that is selected will bring about different interventions to support creative thinking. If a person believes that creativity is domain-general, creativity will be nurtured in general creativities. For example, a picture book can be used to enhance students' divergent thinking in chemistry. On the other hand, if one regards creativity as domain specific, creativity will be fostered within a particular context or area of talent (Plucker, 1998). If creativity is nurtured in a domain, assessment of creativity in that particular domain has to be domain-specific (Baer, 2012).

When exploring the assessment of creativity, most well-known tests evaluate creativity-related skills in a domain general way. Callahan, Hunsaker, Adams, Moore, and Bland (1995) conducted extensive research to inquire which instruments were used to identify gifted students across the United States. In their study, the definition used in identifying gifted students was mostly based on the U.S. Office of Education's (USOE) definition (Marland, 1972) and Renzulli's three-ring conception (Renzulli, 1986). Both of these definitions include creativity. The creativity tests that relied on these definitions were not tied to a domain content-specific creativity, but rather highlighted a skill-related creativity. The result of their search is in agreement with the systematic review of the assessment of creativity conducted by Thys, Sabbe, and Hert (2013). The latter study classified all the studied instruments into the four P dimensions: creative person, creative process, creative product, and creative place/press. None of the instruments contained a specific content in a domain but mainly measured creative thinking skills. A similar finding of creativity assessment emphasizing creative thinking skills in domain generality was confirmed by the review by Cropley (2000).

The two forms of Torrance Tests of Creative Thinking , verbal and figural, which intend to measure creativity, showed low correlation ( $r = .06$ ) (Torrance, 1990, as cited in Cramond,

Matthews-Morgan, & Bandalos, 2005). This implies that different uses of criteria to assess creativity can bring about differentiated abilities or skills in creativity. Simonton (1999) suggested that generalized tests measuring creative thinking skills, such as divergent thinking, lacks predictive validity in comparison with those tailored for a particular domain; that is, divergent thinking must be tailored for each domain (Baer, 2012; Simonton, 1999). Therefore, the assessment of creative thinking skills used to nurture creativity should be devised to elicit sophisticated details of individuals' creative performance in a domain subject.

Because of the lack of a specific content in a domain in the measurement of general creative thinking skills, a Creativity Test in Chemistry (CTC) was developed. This test will allow individuals to apply creative thinking skills to solve problems related to content in chemistry. The test was developed according to the concept of construct map based on the four building blocks (Wilson, 2005).

Wilson (2005) proposed the Four Building Blocks, a systematic process to create a valid and reliable instrument according to defined constructs. When a construct used to create an instrument is defined, a precise construct map based on the construct is generated. The construct map shows qualitative levels of the construct, extending from one extreme to the other. Each level of the construct, such as from low to high; negative to positive; or strong to weak, allows interpretation about how each level of the construct can explain ones' outcomes. Then, items are constructed to assess the construct. An outcome space is defined to indicate how responses can be qualitatively categorized or judged according to the construct. Last, a measurement model is selected to analyze and explicate how the constructs can assess target outcomes.

For example, to understand the construct of knowledge in science for fourth graders, a researcher may select a topic, such as the water cycle. Then, the researcher defines the levels of

knowledge in the water cycle into three qualitative categories, ranging from does not understand the concept, understands part of the concept, and fully understands the concept. Then, an essay is elicited to evaluate the students' knowledge. Students' responses are scored according to the qualitative categories. The Rasch model is chosen to explain student's ability and item difficulty according to the construct. The Rasch model is used to assess categorical data and models the probability of a correct answer as a logistic function of the difference between the person and the item parameter (Rasch, 1980). According to Brown and Wilson (2011), the Rasch model and its associated family of models estimate the persons and test questions (items) in a way that is directly interpretable in terms of the construct map.

The cycle of the Four Building Blocks to create an instrument is shown in Figure 2.1. From the picture, we can see that the cycle represents a continuing process. The cycle starts from construct to measurement model. After the results from the measurement model are obtained, items or outcome space may be modified to better explain the construct. Then, the cycle starts again and repeats until an instrument is determined to be a good representation of the construct.

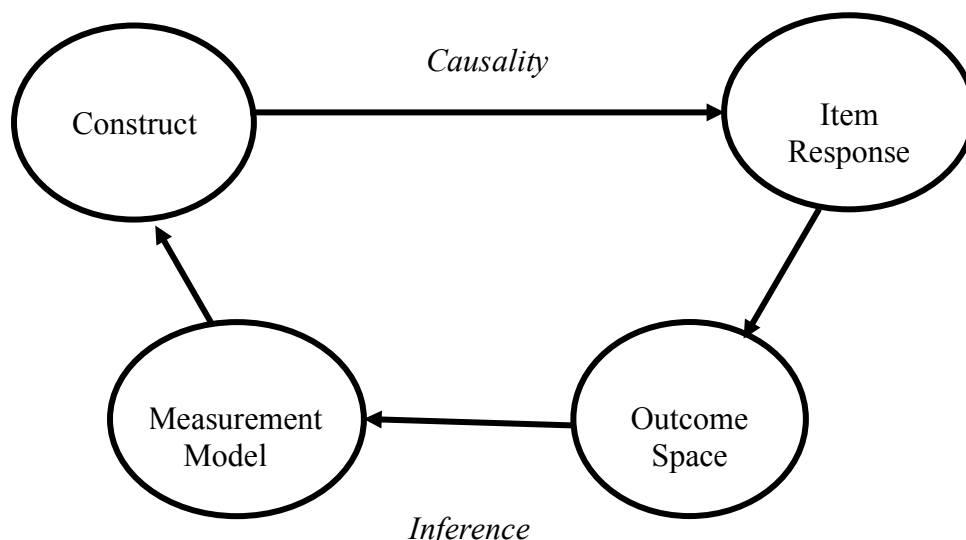
### **Development of the Creativity Test in Chemistry (CTC)**

In this study, the Creativity Test in Chemistry (CTC) was developed according to the Four Building Blocks. The CTC was intended to capture creative thinking skills: the quality of fluency and the association flexibility in the context of chemistry knowledge at the high school level (grades 10–12).

#### **Construct**

In this research, creativity in chemistry was a latent construct. It was defined in terms of the dimensions or constructs of the quality of fluency and the association flexibility. Originality was not directly measured because it was already intertwined in the fluency and flexibility

constructs. Meaning that, the creativity test in chemistry requires participants to generate responses reflecting the quality of fluency and the association flexibility that are original. Test questions that will further describe in the item response section allow such generation of answers. The test seeks not one absolute answer but any possible answers related to the questions.



*Figure 2.1.* The “Four Building Blocks” showing the direction of causality and inference (Wilson, 2005)

In the creativity literature, fluency is defined as the ability to generate many ideas (Torrance, 1990, 2008). However, in the concept of the creative domain of expertise, an accumulation of mental representations, skills, and knowledge is required for individuals to attain a high level of creative performance in a particular field (Ericson, 1999). Therefore, a construct map of the quality of fluency refers to the ability to generate ideas that show levels of knowledge or skills in chemistry.

Flexibility refers to the ability to generate a variety of ideas (Torrance, 1990, 2008). According to Mednick (1962), flat-associative-hierarchy creativity is the ability to connect concepts in a variety of topics or disciplines. Therefore, people who have this ability are more likely to produce varying creative products. On the contrary, those with a steep-associative-hierarchy creativity tend to focus deeply on a specific content, topic, or field and usually contribute a major significance in a particular field. Such people are considered one-shot producers. According to Mednick's assumption, flexibility is hierarchical. It is the ability to form low to high levels of integrative complexity. A construct map of the association flexibility<sup>2</sup> dimension in the CTC is ordered from low to high ability of individuals to combine concepts within or across topics, ideas, theories, or disciplines in chemistry.

The construct map of the quality of fluency and the association flexibility based on the above definitions is shown in Figure 2.2, wherein the quality of fluency is divided into three levels: novice, skillful, and highly competent according to levels of expertise.

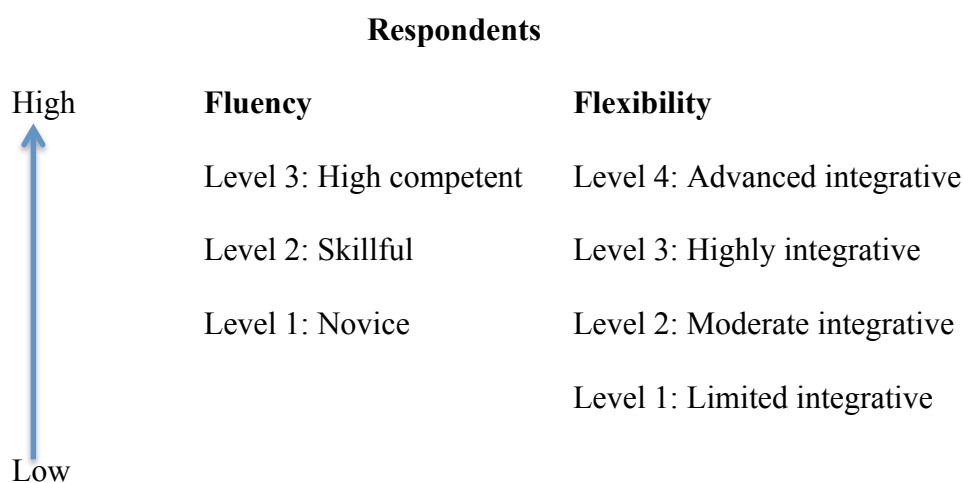


Figure 2.2. The construct maps of the quality of fluency and the association flexibility dimensions

<sup>2</sup> Association flexibility refers to individuals' abilities to combine concepts within or across topics, ideas, theories, or discipline in chemistry according to defined categorical levels.

When a person learns new skills, he or she develops from novice to various higher levels of expertise until he or she becomes an expert (Clark, 2008). Therefore, the greater is one's ability to generate high levels of knowledge, the higher is his or her location in the construct map. Similarly, for the association flexibility, the construct map ranges from having a limited ability to combine concepts to having the ability to combine concepts across disciplines: limited, moderate, high, and advanced integrative.

### **Item Responses**

The format of the CTC was open-ended questions. The main basis of the test relied on a well-known creativity test of Torrance, the Torrance Tests of Creative Thinking—Verbal Form (Torrance 1990, 2008), which included the following tasks: asking questions, guessing causes, guessing consequences, product improvement, unusual uses, and just suppose. He designed the tasks on the test similar to the tasks of the scientific method: asking questions, forming hypothesis, experimenting, and making conclusions. Because it is a test of scientific creativity, Torrance's tasks seemed appropriate for this test. Items in the test included major topics found in a high school chemistry curriculum, such as the periodic table, chemical reactions, plastics, and behavior and properties of matter. Participants would answer questions based on their own levels of knowledge and creativity. Items on the creativity test in chemistry according to the construct are presented in Table 2.1.

To assure the validity of CTC, the test was emailed to three experts in chemistry and two high school chemistry teachers. They were asked to rate their opinions about the appropriateness of the items. The test reviewer received the rationale about the test and research objectives. Emails were sent back and forth between the researcher and the experts to clarify any questions

or concerns an expert had in relation to the test. Based on the feedback from the experts, items were adjusted in terms of wordings and meanings.

Table 2.1

*The Construction of Items in Creativity Test in Chemistry (CTC)*

Construction of Test	Items
Asking	1. If you had a chance to meet with a well-known scientist(s) from the past or present, what observations or questions regarding their knowledge of chemistry would you like to ask them? Why would you ask them that question? What do you expect you would do with their response to the questions? Would the response help you, your family, your country, or all of humanity?
Guessing causes	2. In an experiment, if your chemical reactions did not come out as you expected, what would you speculate could be the causes of the unexpected results regarding the reactions? What would you do to confirm that your ideas were correct?
Guessing consequences	3. If you have three types of clear liquids with no color, how would you identify the properties and chemical nature of those liquids? Describe the steps you would take, and discuss the possible outcomes.
Product improvement	4. Nowadays, plastics are widely used. How can you use your knowledge of <b>chemical properties</b> or <b>reactions</b> to improve the qualities of the plastics we use in different forms? How could plastic products be more useful or appropriate for our utilization?
Unusual uses	5. From the chemical properties you have learned, do you think there are atoms or molecules that could be substituted for one another in order to study, test, or create chemical reactions? If so, why? What could you use this knowledge for?
Just suppose	6. Suppose all the atomic numbers of atoms on the periodic table increased by 1, how would that affect the knowledge you have learned in chemistry? What interesting things could you do with the new knowledge?

## Outcome Spaces

According to Brown and Wilson (2011), outcome spaces show details about how participants' responses are located according to qualitative categorical levels of a construct map. Outcome spaces are tools to facilitate the process of scoring. Their categorical scoring or valuing of responses ensures that scores are meaningfully relevant to the latent construct of creativity in chemistry.

In the CTC, each question was scored on two dimensions: the quality of fluency and the association flexibility. The quality of fluency is defined as the ability to generate a number of responses demonstrating levels of knowledge in chemistry. Each response is scored according to the construct map of the quality of fluency, with scores ranging from zero to three. The range of scores indicates one's ability: not fluent, novice, skillful, and highly competent. The association flexibility refers to the ability to generate a lot of responses showing a combination or combinations of concepts within or across disciplines. The scores range from zero to four, which indicate having flexibility, limited integration, moderate integration, high integration, and advanced integration. The explanation for each level of each construct and scoring is presented in Table 2.2.

Among the scored answers for each question, the best score for the quality of fluency and the association flexibility dimensions will represent the scores for the two dimensions for a particular question. To illustrate, a participant generates three responses in question one. He or she will thus earn three different scores for each construct map. If his or her best score is two for the quality of fluency and three for the quality of flexibility, his or her scores in question one will be two and three, respectively, no matter what other scores he or she got for the first question.

Table 2.2

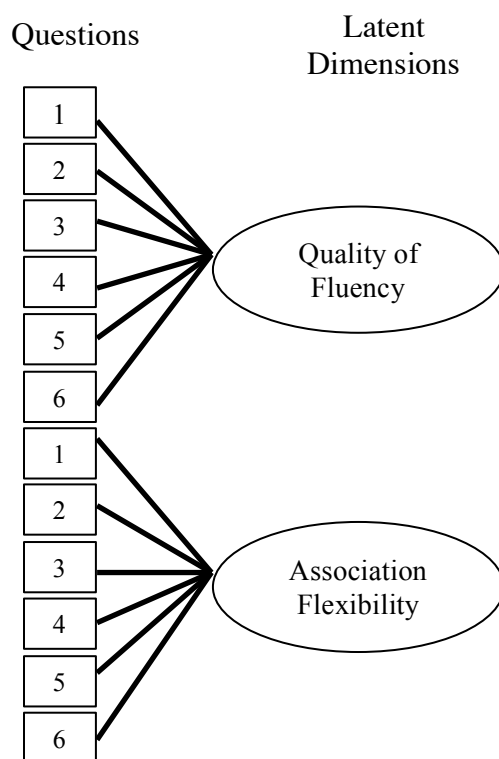
*The Construct Map and Outcome Space of the Two Dimensions: the Quality of Fluency and the Association Flexibility*

Respondents	Responses to questions	Examples of responses	Scores
Quality of Fluency			
Highly competent	Generating Responses different from what told in textbook or show evidence of knowledge beyond high school level.	Q3: Apply sodium fusion to analyze elements in atoms.	3
Skillful	Responses demonstrate understandings of facts/concepts/ideas with supporting ideas.	Q2: Evaporate liquid and check whether there was a solid object left.	2
Novice	Responses show simple facts/concepts/ideas with limited explanations.	Q5: Benzene can be in lieu of Hexane.	1
No Fluency	Responses are incorrect or irrelevant to the question. Or, questions are simply answered by chemistry textbooks.	Q1: could a scientist make time machine?	0
Association Flexibility			
Advanced Integrative	Responses integrate a concept beyond high school chemistry knowledge or combine concepts different from what told in chemistry textbooks. The combination of concepts is across disciplines.	Q4: Develop plastic organs that can be infused in human body and are not against immune system.	4
Highly Integrative	Responses integrate a concept beyond high school chemistry knowledge or combine concepts different from what told in chemistry textbooks. The combination of concepts is not across disciplines.	Q6: If there were no hydrogen, there would have no acid substances or water. A study had to be done to find the other element substitute for it.	3
Moderate Integrative	Responses show elaborative combinations of facts/concepts/knowledge related to a question.	Q5: Catalysts, such as MnO <sub>2</sub> and Pb can be interchangeably used as they accelerate chemical reactions.	2
Limited Integrative	Responses show at least a linkage concepts related to a question.	Q3: Test acidity with Litmus.	1
No Flexibility	There is no linkage of concepts shown in the responses.	Q1: how was an element discovered?	0

### Measurement Model

The multidimensional random coefficients multinomial logit (MRCML: Adams, Wilson, & Wang, 1997) model is a powerful model framework for Rasch measurement. A between-item multidimensionality model (Briggs & Wilson, 2003) was used to estimate participants' abilities and item location according to the Rasch Model (Rash, 1960, 1980). The model estimates all the parameters from the two constructs: the quality of fluency and the association flexibility jointly.

Figure 2.3 showed the use of between-item multidimensionality in the context of the creativity test in chemistry.



*Figure 2.3.* Between-item multidimensionality of CTC.

This model was suitable for the CTC because the test measured two constructs: the quality of fluency and the association flexibility. In Figure 2.3, questions one through six were scored two times based on the outcome spaces in Table 2.2 for the two dimensions.

### **Research Questions**

1. Are there two constructs, the quality of fluency and the association flexibility, in chemistry as measured by the CTC?

2. Does the CTC have acceptable levels of reliability and validity?

## Method

To study how the creativity test in chemistry based on the defined constructs was valid and reliable for future use in chemistry or classroom, the test was implemented according to the following methods.

### Participants

Participants were Thai 11-12th graders, undergraduates, and professionals, whose majors or interests are in physics, chemistry, biology, and mathematics. High school students were from different schools and gifted projects. Juniors, seniors, and professionals were from Development and Promotion of Science and Technology Talents Project (DPST). The total participants in this study were 528. Participants were invited to be involved in the research by email. Participation was on a volunteer basis. The demographic data of participants are presented in Table 2.3.

Table 2.3

#### *Demographic Data of Participants*

	Frequency	Percent
Gender		
Female	336	63.6
Male	184	35.4
Level		
High School	326	61.7
University	130	24.6
Profession	72	13.6
Majors		
Physics	157	30.5
Chemistry	164	31.8
Biology	174	33.8
Mathematics	20	3.9

### Instrument

The Creativity Test in Chemistry (CTC) was created with Qualtrics software and administered online. The test consisted of 6 questions, and participants had 10 minutes to

complete each question. The sequence of the questions was consistent to every participant. They could leave a question if their test time reached 8 minutes. If they could not finish the question within 10 minutes, another question would instantly pop up. They could not go back to complete an item once a new question appeared. The test was distributed online with specific links in accordance with participants' emails. Participants would receive a reminder every two weeks.

Before the participants began taking the creativity test in chemistry, they had to read the instruction and finish a warm-up activity. The instruction informed the participants about the total number of questions, the amount of time they had to finish each question, and the traits of creativity—fluency, flexibility, and originality—that the test intended to measure. The instruction explained fluency as the ability to generate many answers that showed the participants' knowledge in chemistry; flexibility as the ability to form ideas illustrating different groups of concepts, ideas, or theories related to their knowledge of chemistry; and originality as the ability to provide ideas against mainstream knowledge related to chemistry. Although the participants' responses were not scored for originality, the description of originality is important to encourage the participants to initiate unique ideas.

The test instruction also informed the participants that there would be no right or wrong answers. They were encouraged to provide as many answers as possible related to the questions according to the traits for each question. The warm-up activity asked the participants to provide many answers about what were red things in nature. The participants were required to score their answers according to the details of the three traits provided; otherwise, they could not begin the real test. The activity aimed to familiarize them with the types of questions that did not require absolute answers but rather possible answers. The test took 5 minutes to complete.

## Scoring

Participants' CTC responses were scored according to the outcome space as described earlier and in Table 2.2. The response to each question was scored for two dimensions: the quality of fluency and the association flexibility.

For example, in question one, a respondent was asked to provide several answers to questions he or she would like to ask scientists in relation to chemistry. His or her answer was scored according to the levels in the two construct maps. To illustrate, if his or her answer showed a high level of knowledge beyond his or her knowledge of high school chemistry, a score of three according to the construct map of the quality of fluency was obtained. If his or her answer did not demonstrate a linkage of learned concepts at the high school level, a score of zero was assigned according to the scoring of the construct map of the association flexibility.

Participants were asked to generate many answers for each question. This meant that for each question, participants would earn different scores for the answers that they provided. Only the best score for each construct map for each question was representative of the score for that question. Strictly speaking, one question would have two best scores: one representing the score according to the construct map of the quality of fluency and the other referring to the scoring based on the construct map of the association flexibility. The statistical values of raw scores from CTC are presented in Table 2.4.

The researcher was the only person who scored the CTC. Scoring was refined over several iterations. The process of improvement involved scoring participants' tests according to the outcome space in Table 2.2; running analysis for the two types of models, unidimensional and two-dimensional, to check reliability; and adjusting the outcome space or scoring. This process is part of the development in the Four Building Blocks shown in Figure 2.1, in which an

outcome space is developed to better capture the latent construct, creativity in chemistry.

Table 2.4

*Statistical Values for the Scores according to the Two Dimensions: the Quality of fluency and the Association Flexibility*

Dimension	Questions	Mean	SD	Range
Quality of fluency	1	1.45	0.89	3
	2	1.01	0.73	3
	3	0.93	0.99	3
	4	1.20	0.92	3
	5	0.75	1.02	3
	6	0.81	0.75	3
Association flexibility	1	1.50	1.32	4
	2	1.20	1.08	4
	3	0.98	1.12	4
	4	1.29	1.37	4
	5	0.94	1.33	4
	6	0.86	1.13	4

### Analysis

Conquest 2.0 (Wu, Adams, Wilson, & Haldane, 2007) was used to analyze data according to the Rasch model. First, the program was used to run a unidimensional model in which the scores from the two dimensions—quality of fluency and association of flexibility—were combined as one dimension of creativity. Then, a two-dimensional model in which the scores from the quality of fluency dimension and those from the association flexibility dimension were treated as two different constructs. The comparison between the two models was made to identify whether the CTC actually consisted of two dimensions as hypothesized. The delta dimension alignment (DDA) technique (Schwartz, 2012) was also used in Conquest 2.0 for the alignment of the two models— unidimensional and two-dimensional—to make a comparison across dimensions.

The MRCML model assumes that student ability estimates on each dimension are constrained with the mean of zero (Adams, Wilson, & Wang, 1997). In this study, in order to compare student ability estimates across the two constructs, the DDA technique is used. The DDA starts with a command of constraining cases in a unidimensional model to obtain the mean and SD of the item difficulties from each subdimension. Equation 2.1 is then applied to transform the difficulties from the multidimensional analysis to have the same mean and SD as the relevant item sets in the unidimensional analysis. Equation 2.2 is used to transform the step parameters from the multidimensional analysis. All transformed difficulties and step parameters were anchored in the second multidimensional analysis with none constraint the mean of student ability estimates to be zero.

Item location:

$$\delta_{id(\text{transformed})} = \delta_{id(\text{multi})} \left( \frac{\sigma_{d(\text{uni})}}{\sigma_{d(\text{multi})}} \right) + \mu_{d(\text{uni})} \quad (2.1)$$

Step parameters:

$$\tau_{ikd(\text{transformed})} = \tau_{ikd(\text{multi})} \left( \frac{\sigma_{d(\text{uni})}}{\sigma_{d(\text{multi})}} \right) \quad (2.2)$$

Lastly, the differential item functioning (DIF) technique (Adams, Wilson, & Wang, 1997) was analyzed in Conquest 2.0. DIF was used to explore the existence of different response probabilities when a test item cannot fully explain the abilities of the students and test item difficulties. Gender, levels of expertise, and areas of study were sought to further explain different response probabilities among participants. The results from DIF provided an evidence of *validation based on external relations*.

## Results

### Descriptive Statistics of Scores from the CTC

The descriptive statistics of scores from the CTC were presented based on the types of scores used for the unidimensional and multidimensional analyses. In this research, “multidimensional model” refers to a two-dimensional analysis. Total scores, in which scores from the dimensions of the quality of fluency and the association flexibility were combined, were used for the analysis of the unidimensional model. The sums of scores from each dimension, the quality of fluency and the association flexibility, were employed in the two-dimensional analysis. Table 2.5 shows the descriptive statistics of scores from the CTC.

Table 2.5

#### *Descriptive Statistics of Raw Scores on the CTC*

Scores on CTC	Min	Max	Mean	SD	Skewness	Kurtosis
The quality of fluency	0.00	17.00	6.16	3.40	.890	.379
Association flexibility	0.00	23.00	6.70	4.89	.768	-.054
Total scores	0.00	38.00	12.87	8.07	.809	.084

*Note:* Total scores = High scores on the quality of fluency and on the association flexibility from each participant were summed.

### Model-data Fit

The comparison between the unidimensional and the 2-dimensional model was made by the change in their deviance. The greater the likelihood, the closer the fitted model is to the true model. The negative log likelihood (logarithm of likelihood or deviance) is an index of the difference between the estimated model and the true model. Therefore, small deviance is expected and models with smaller deviances are chosen (Janssen & De Boeck, 1999). The

significant change in deviance is considered, this is based on the Chi-square distribution with the number of parameters and degrees of freedom (Briggs & Wilson, 2003).

Table 2.6

*Global Fit Statistics and Information Criteria for the Models*

Models	$G^2$	Change in $G^2$	# of parameters	AIC	BIC
1-Dimensional	13386.2242	-	43	13472.2242	13503.2975
2-Dimensional	13377.1556	9.0686	45	13467.1556	13499.6741

*Note.*  $G^2$  = deviance. # = the number.

Table 2.6 shows that the two-dimensional model had a smaller deviance than the unidimensional model. The change in deviance from the unidimensional model to the two-dimensional model was statistically significant ( $G^2 = 9.0686$ , \*  $p < .05$ ), indicating a better fit of the two-dimensional model compared to the unidimensional model. Akaike information criteria (AIC) (Akaike, 1974) and Bayesian information criterion (BIC) (Schwarz, 1978), which are based on the deviance, the number of estimated parameters, and sample size also supported a good fit of the two-dimensional model due to smaller values in AIC and BIC.

Since the two-dimensional model had a good fit, the results of the dimensional analysis from DDA are interpreted. From, the DDA analysis, the correlation between the two dimensions is .991, which is very high. This high correlation may cause the estimates of the two dimensions not to be distinctly different.

### **Wright Map**

Wright Map as shown in Figure 2.4 describes the distribution of participants' ability estimates and the difficulty of the item for the two dimensions. For each dimension, the left side

of the map shows the distribution of the estimated participants' ability, the items on the right side of the map are distributed from the most difficult at the bottom to the least difficult at the top.

From Figure 2.4, participants' abilities from the two dimensions have a high correlation ( $r = .991$ ). However, the distribution of the first dimension is flatter and has longer tails compared to that of the second dimension. That means participants' ability in the first dimension is more spread than in the second one.

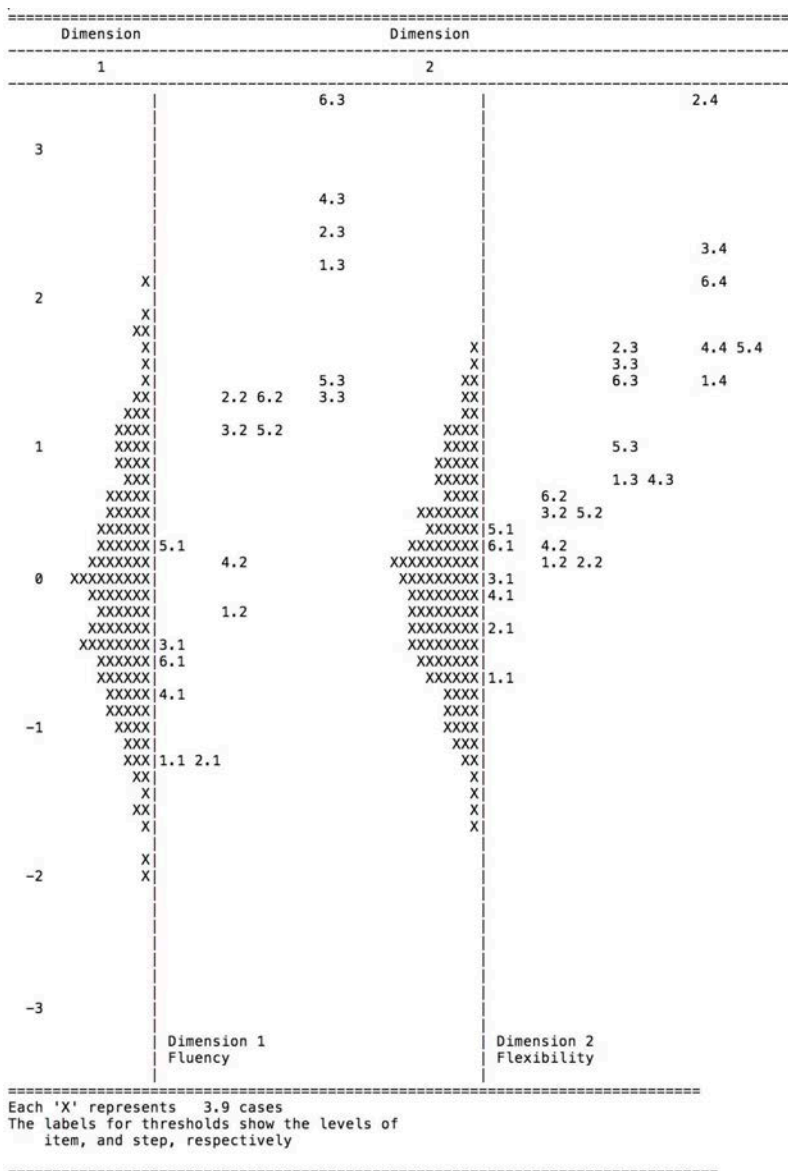


Figure 2.4. The Wright map for the two dimensions of CTC

As shown in Figure 2.4, the distributions of item difficulty are above the distribution patterns of participants' abilities, this indicates that the ability of participants is less than the difficulty of the item. Therefore, most participants have less than 50% chance in answering items correctly. More specifically, there is less than 50% chance that most participants can accomplish at the high thresholds of both dimensions (third threshold of the first dimension, and third and fourth thresholds of the second dimension). Further evidence is shown by the small number of participants whose abilities are located at those thresholds. Simply speaking, the test might have been too difficult for the participants.

Item difficulty location in both dimension one and dimension two shows some overlapping. For the first dimension, score categories overlap with every category. However, score categories two and three are more separate than score categories one and two. There is also an overlapping of score category in the second dimension. Score categories one, two, three, and four are clustering. Nevertheless, it seems that score category three is separate from score category two, but the separation is not obvious as there is little space between the two categories.

From the item thresholds shown in Figure 2.4, it takes more ability to complete items at high score categories. This information corresponds with the increasing values of item difficulties for lower to higher thresholds in each question as presented in Table 2.7.

In addition to explaining the relationship between participants' abilities and item difficulties on the CTC, the Wright Map in Figure 2.4 can be used to interpret each participant's ability in relation to item difficulty. Table 2.8 provides examples of six participants whose raw scores and total raw scores are matched with estimated ability scores for a clearer understanding of the relationship. For example, the participant no. 421 has a raw score of 6 and an estimated ability score of -.004 in the quality of fluency dimension. With that ability score, the participant

has more than a 50% chance to generate the quality of fluency at threshold one for every question, with the exception for question five. That person has more than a 50% probability to complete at threshold two for the first question as well. Such probability resonates to the information in Table 2.7, demonstrating that the person has the ability to achieve at the first and second threshold for certain questions because his or her ability score is greater than the values of item difficulty.

Table 2.7

*The Item Threshold Statistics of the Quality of Fluency and the Association Flexibility*

Dimensions	Questions	Overall Item difficulty	Estimated Item Threshold				
			1st	2nd	3rd	4th	
1 (Quality of Fluency)	1	0.25	-1.25	-0.23	2.22	-	
	2	0.84	-1.27	1.28	2.52	-	
	3	0.63	-0.43	1.04	1.27	-	
	4	0.73	-0.74	0.16	2.76	-	
	5	0.88	0.22	1.03	1.39	-	
	6	1.45	-0.34	1.24	3.44	-	
	Statistics	Mean	0.80	-0.64	0.75	2.27	-
		SD	0.39	0.57	0.63	0.83	-
		Min	0.25	-1.27	-0.23	1.27	-
		Max	1.45	0.22	1.28	3.44	-
		Range	1.20	1.49	1.51	2.17	-
2 (Association Flexibility)	1	0.43	-0.65	0.18	0.77	1.42	
	2	0.48	-0.36	0.16	1.64	4.08	
	3	1.10	-0.01	0.49	1.51	2.40	
	4	0.32	-0.13	0.32	0.78	1.64	
	5	0.90	0.36	0.56	1.02	1.64	
	6	1.11	0.23	0.64	1.48	2.10	
	Statistics	Mean	0.72	-0.09	0.39	1.20	2.21
		SD	0.36	0.37	0.20	0.39	0.98
		Min	0.32	-0.65	0.16	0.77	1.42
		Max	1.11	0.36	0.64	1.64	4.08
		Range	0.79	1.01	0.48	0.87	2.66

Similarly, participant no. 412 also earns a raw score of 6 and an estimated ability score of .036 in the association flexibility dimension. This participant is probably 50% able to create association flexibility answers at threshold one for questions one to four according to the Wright Map because his ability .036 is greater than the values of item difficulty for those questions, as shown in Table 2.7. In summary, we can infer that at lower abilities of -.004 and .036, this participant is more likely to achieve only at the first threshold for the two dimensions.

Table 2.8

*Examples of Raw Scores and Ability Scores on CTC*

# Participant	Raw scores		Total raw scores	Ability scores	
	Quality of fluency	Association flexibility		Quality of fluency	Association flexibility
47	5	7	12	-.028	.026
123	6	7	13	.468	.438
326	6	2	8	-.391	-.305
421	6	6	12	-.004	.036
477	6	7	13	.082	.112
489	6	9	15	1.305	1.157

*Note.* # participant = the number of participants.

Nevertheless, from Table 2.8, participants will possess different estimated ability scores, even if their raw scores are equal within the same dimension and across the dimensions. For example, at a raw score of 6 for the dimension of the quality of fluency, participants obtain different ability scores, i.e., .468, -.391, -.004, .082, 1.305. Participants' ability scores vary because the Rasch model takes into account item difficulty. With this advantage of the Rasch model, we can locate a person's ability score, such as -.004, on the Wright Map and understand where that person's ability is located. This allows educators the ability to help that person improve by using the information that is gained from the Wright Map. In this specific case of that ability at -.004 for the first dimension, the person was more inclined to generate the quality

of fluency at the first threshold, except for question five. This person only accomplished at the second threshold for only the first question. This means that this person was a novice because most of his or her answers only show simple facts/concepts/ideas with limited explanations, shown in Table 2.2. With this information, we should encourage this student to achieve at higher levels of the quality of fluency. The same interpretation can be done for the second association flexibility dimension.

As the DDA technique allows comparison across the two dimensions, we can also examine the total raw scores of participants to compare with their estimated ability scores in the two dimensions. With this comparison, we can tell how participants performed on each dimension. For example, in Table 2.8, at a total raw score of 12, the participant no. 47 earns the estimated ability scores of  $-.028$  and  $.026$  for the two dimensions, respectively. This person seems to have a higher comfort level in generating the quality of fluency answers, as his or her ability score on the first dimension is lower than the second dimension. With an ability score for each dimension, a person's ability can be thoroughly understood through the Wright Map for improvement with the same interpretation as described previously.

### **Reliability, Correlations, and Validity**

CTC has high reliability as shown by high values of separation reliability and Cronbach's Alpha, which are 1.00 and .79, respectively.

From table 2.9, the two dimensions have almost identical reliability, which are .815 and .816, respectively. The standard deviation for dimension one is .038 and .032 for dimension two. The mean of the two dimensions is  $-.019$  for the first dimension and  $.027$  for the second dimension. The mean values from the two dimensions shows that items in dimension one are

easier than those in dimension two, and participants are more capable in generating answers to questions in the first dimension than for those in the second dimension.

Table 2.9

*The Statistics of the Two-Dimensional Model*

	Dimension 1 (Quality of Fluency)	Dimension 2 (Association Flexibility)
Reliability	.815	.816
Mean (Ability)	-.019	.027
SD (Ability)	.038	.032

### Validity

**Validity based on internal structure.** According to the weighted fit mean square values in Table 2.10, all items are in the acceptable range, this indicates a good fit. The commonly used values of 95% confidence interval are .75 to 1.33 (Adams & Khoo, 1996), in relation to a sample size of around 100. Items with a good fit have the average discrimination power to discriminate low and high achievers.

Table 2.10

*Item Fit Estimates*

Dimensions	Questions	Estimate	Unweighted Fit			Weighted Fit		
			MNSQ	CI	T	MNSQ	CI	T
1	1	.254*	1.10	(.88, 1.12)	1.5	1.08	(.89, 1.11)	1.4
	2	.839*	.87	(.88, 1.12)	-2.2	.87	(.87, 1.13)	-2.1
	3	.588*	.92	(.88, 1.12)	-1.2	.93	(.87, 1.13)	-1.0
	4	.731*	1.12	(.88, 1.12)	1.8	1.07	(.89, 1.11)	1.2
	5	.857*	.81	(.87, 1.13)	-3.0	.87	(.85, 1.15)	-1.8
	6	1.446*	1.01	(.87, 1.13)	.1	.96	(.88, 1.12)	-.7
2	1	.425*	1.17	(.88, 1.12)	2.6	1.13	(.89, 1.11)	2.1
	2	1.395*	.90	(.88, 1.12)	-1.6	.92	(.90, 1.10)	-1.6
	3	1.107*	.97	(.88, 1.12)	-.4	1.00	(.88, 1.12)	.01
	4	.665*	1.05	(.88, 1.12)	.7	1.04	(.88, 1.12)	.7
	5	.920*	.90	(.87, 1.13)	-1.5	.95	(.86, 1.14)	-.7
	6	1.120*	1.09	(.87, 1.13)	1.4	1.03	(.86, 1.14)	.5

*Note.* \*An asterisk next to a parameter estimate indicates that it is constrained. MNSQ = mean square. CI = confidence interval.

**Validation based on external relations.** The impact of gender on the creativity test was studied. The actual parameter estimate for the male participants was almost three times larger than its standard error estimate, so the difference between the female and male was obviously significant. The chi-square value of 6.27 on one degree of freedom was consistent with this finding. The conclusion was that the mean performance of males was lower than that of females. The result also showed that forming the quality of fluency ideas on question two was relatively easy for males than females, while generating the association flexibility ideas on question two was more difficult for males than females. The differences on mean performance between males and females were not obvious in other items as the parameter estimates were not far greater than their standard error values.

Levels of expertise: high school, undergraduate, and professional were investigated. The standard error of undergraduate students is two times greater than its estimates. Therefore, undergraduate students had a more difficult time taking the test than other participants. Different levels of participants had varying responses to particular questions. It was easier for high school students to generate the quality of fluency ideas on item 5 than other levels. Undergraduate students had difficulty performing the quality of fluency ideas on questions 2 and 4 and flexibility on question 4. Professionals found it hard to form the quality of fluency ideas on questions 5 and 6 but were comfortable in coming up with the association flexibility ideas for questions 1 and 2.

Different areas of scientific study: physics, chemistry, and biology had particular responses to the test and questions as well. Overall, biology majors found it difficult to take the test as the standard error was twice than the estimate. Biology majors had a hard time forming the quality of fluency ideas on questions 1, 3, and 5 and the association flexibility ideas on

questions 11. For question 1, participants in physics and chemistry found it difficult to form the association flexibility ideas. Physics majors and chemistry majors were comfortable in generating the quality of fluency ideas on questions 5 and 3, respectively. Nevertheless, it was difficult for physics majors to come up with the association flexibility ideas on question 2.

### **Validation based on consequences for the two dimensions measured in the test.**

Respondents volunteered to complete the test. Their responses were based on their understanding of what the intention of the test was and whether they were familiar with the type and style of test. The test style might not meet their expectation, as it was not a usual style of test used in a school setting. From the pilot study, the problem with item fit occurred for item sets presented to respondents first more than alternate items mostly presented after item sets. It could be assumed that students might have been more comfortable to respond to the style of the test after they experienced some items. So, in order to help students succeed in this test, succinct practices of the test may be introduced to test takers.

Additionally, this test was intended to measure how well participants could think creatively in the subject of chemistry. Participants' test scores should only be interpreted for the improvement of creativity in chemistry and not as a criterion to assess the overall creativity of an individual.

### **Conclusions and Discussion**

The two-dimensional model was significant, confirming that measuring creativity in chemistry has two dimensions: the quality of fluency and the association flexibility. This result was in accordance with the structure of intellect (Guilford, 1959). The structure can be conceptualized as a three-dimensional cube by which intellectual operations, contents and products form each of the dimensions. According to this viewpoint, divergent thinking abilities

(fluency, flexibility, elaboration, and originality) are generalized abilities that can be applied to different categories of content in order to produce a variety of products. To understand and develop creative thinking skills in chemistry, fluency and flexibility skills should be considered. Due to participants using divergent thinking skills to provide solutions in the specific domain of chemistry, creativity can also be viewed as domain generality.

However, the high correlation between the two dimensions: the quality of fluency and the association flexibility is concerning. Although the two-dimensional model shows a better significant fit than the unidimensional model in which fluency and flexibility scores are combined as one dimension, this problem should be fixed. The overlapping scores in fluency and flexibility also happened to Torrance Tests of Creative thinking on Figural form. Dr. E. Paul Torrance. The Torrance Tests of Creative Thinking have been used and developed for more than 40 years. His tests were based on divergent thinking of Guilford, who considered deleting flexibility scoring from the figural test and added new normed-referenced scores to his test due to the high correlation between the fluency and flexibility scores (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005).

As a result, to improve the quality of this creativity test in chemistry, an ongoing process with the Four Building Blocks with this test should be further implemented. The scoring may need to be adjusted as the Wright map shows some overlap in categorical levels of scores. More items may be created and scored for one dimension rather than two dimensions as this test's scoring shows. Item difficulties may be adjusted as the Wright map indicated that items were quite difficult than participants' ability. Or, new criteria for considering creative thinking skills in this test may be integrated.

Another point worth discussing is the style of the test. The creativity test in chemistry was open-ended questions that required multiple possible responses. The style of the test was new in a domain subject, chemistry. Some participants liked this test style as it allowed them to connect and form unique ideas; others thought these questions were difficult and too imaginative. High school students were more likely to favor this test than undergraduates and professionals. In my opinion, it is interesting to integrate this style of questions to measure creative thinking skills and levels of knowledge acquired in a domain. There was a possibility to use this style of test to capture students' creativity and knowledge in several topics of domain subjects. From the systematic review about the assessment of creativity in creativity and psychopathology research (Thys, Sabbe, & Hert, 2013), the most frequently used measures were categorized into four groups: the creative person, the creative process, the creative products, and the creative place/press. All the tests shown in this study were content free. Therefore, the promotion of using creativity in a domain subject should be supported.

The other interesting point to be raised is the differences in mean performance when gender, levels of study, and science areas were taken into account. Participants with different demographic information: gender, levels of expertise, and branches of science had particular responses to all of the questions. The particular responses maybe the result of the participant's unfamiliarity of the style of tests. Another possible cause is the participant's varying preferences to form fluent or flexible ideas. This result may provide awareness for the use of the creativity in chemistry in some certain groups.

CHAPTER 3  
A STUDY OF DOMAIN SPECIFICITY AND GENERALITY OF CREATIVITY AND  
PERSONALITY AMONG SCIENCE MAJORS<sup>3</sup>

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<sup>3</sup> Sricharoen, N. To be submitted to *Gifted Child Quarterly*.

### Abstract

The study was intended to explore the nature of creativity in Thai people in different science fields and at different levels of expertise. Specifically, I looked at (1) the nature of creativity, whether domain specific or general; (2) personalities of creative people in different sciences and levels; and, (3) the engagement in activities related to science. In order to investigate these things, the Creativity Test in Chemistry (CTC), the Torrance Tests of Creative Thinking (TTCT-V), the Gough Personality Scale, and the Activity Check List of the Runco Creativity Assessment Battery (rCAB) were used. Due to the low correlation,  $r = .164$  ( $t = 2.451$ ,  $* p < .05$ ), between the two dependent variables: scores from CTC and scores from TTCT-V, a separate 2 way-ANOVA for each dependent variable was analyzed. Two-way ANOVA results revealed that for the CTC, participants in chemistry at all levels of expertise performed better than other majors: physics and biology as indicated by significant interaction ( $F = 4.2171$ ,  $* p < .05$ ). However, for the TTCT-V, the two-way ANOVA showed that both high school students and professionals performed better than the undergraduate students,  $* p < .05$ . The Principal Component Analysis (PCA) from the Gough Personality Scale suggested eight personality factors, namely confidence, insight, sincerity, creativity, nonconformity, skepticism, humility, and narrow interests at eigenvalues 1.124 with 61.311% accumulated variance. A profile of creative characteristics of this group from cluster analysis provided three clusters based upon the average value of Silhouette .4, namely high ability group, competent group, and low ability group. There were significant differences in mean scores on the two tests between the competent and the low ability group. There was no significant difference among activities related to science in which the three groups were engaged. However, there was a significant difference in a personality factor: skepticism ( $F = 3.807$ ,  $* p < .05$ ) between the competent and the low

ability group, with higher scoring in skepticism in the competent group compared to the low ability group.

**Keywords:** Creativity, Scientifically creative personality, Science and creativity, Chemistry and creativity, Torrance Tests of Creative Thinking, Verbal form (TTCT-V), Gough Personality Scale, Activity Check List of the Runco Creativity Assessment Battery (rCAB)

A specific viewpoint about whether creativity is domain general or specific provides implications for how it will be applied to support individuals' creativity. If creativity is viewed as domain general, then creative thinking skills will be trained without a concern for specific content. This belief assumes that creative skills are transferable across domains (Guilford, 1959; Hocevar, 1976; Milgram 1990; Plucker, 1998; Torrance, 1966). However, if one regards creativity as domain specific, then creative skills need to be fostered within a particular context or area of talent. Baer (1998) supported that divergent thinking should be integrated to train individuals in specific domain tasks.

There have been attempts to uncover whether creativity is domain general or specific. Hocevar (1976) asked participants to rate their creative activities and achievements in six different dimensions: fine arts, crafts, performing arts, math-science, literature, and music. He summarized that low to moderate correlations among the dimensions were an indication that creativity is a domain general trait. Along the same line of research, Baer (1974) required each participant in his study to create different products: telling stories, writing stories, writing poems, writing mathematical word problems, and making collages. His conclusion was that low correlations among different products generated by an individual showed evidence of the domain specificity of creativity.

In these two studies, the problem with using correlations among different products or achievements as criteria to identify whether creativity is domain general or specific is that it is doubtful. The low correlations were interpreted either as evidence of general traits of creativity or domain specificity. These inconclusive conclusions about correlated results did not clearly identify the definition of creativity. This paradoxical interpretation may be due to the use of

correlation to answer research questions. Correlation provides information on the importance of the relationship among variables, but cannot explain the causal relationship among variables.

Hong and Milgram (2010) conducted a study to investigate the correlation between domain-general and domain-specific creativity by using structural equation modeling. Ideational fluency measured by the Tel Aviv Creativity Test (TACT) was used for assessing domain-general creative thinking ability, while the Ariel Real-Life Problem Solving (ARLPS) was used to indicate participants' fluency when specific life situations were presented. The findings indicated that general creative thinking had a positive direct effect on specific creative thinking when the effects of grade and gender were controlled.

Cassain, Davidovitch, and Milgram (2010) studied idea fluency as a creative thinking skill with selected items from the Tel Aviv Creativity Test (TACT) and with the Real-Life Problem Solving: Architecture (RLPS:A). The two tests were assessed to be domain generality and specificity, respectively. They are divergent thinking tests as participants are required to generate as many answers as possible. In addition, TACT has two forms: verbal and figural, while RLPS:A has only a verbal form. Scores on the verbal component of the TACT were moderately correlated with those on the RLPS:A ( $r = .51$ , \*\*\*\*  $p < .001$ ).

Along the same line in investigating domain generality or specificity of creativity, Hong and Milgram (2010) designed a study to clarify the definition of creativity by requiring participants to apply divergent thinking skills to solve problems in the TACT, an assessment of everyday life problems and in specific life situations as a measurement of domain specificity of creativity. Cassain, Davidovitch, and Milgram (2010) applied the same design to tackle the definition of creativity. They also used the TACT as a way to assess divergent thinking skills in everyday life problems, but their selection of specific life situations as an instrument for domain

specificity solely focused on architecture. Both studies required the same skill: divergent thinking of participants to solve problems.

Questions in RLPS:A (Cassain, Davidovitch, & Milgram, 2010): ask participants to generate architectural knowledge as many as they can. For example, one of the test questions asked the participants to generate the architectural mean by solving the problem of making an underground market visible. However, some specific life situation problems requiring participants' specific knowledge in domains are still general problems. The specific life situation questions do not require learned content knowledge in a domain. As an example to illustrate this, a specific life situation question in math asked participants to suggest as many solutions or ideas as possible when John was well-prepared for the final test in basic mathematics but could not remember anything he reviewed after getting the test form on the day of the test. Questions that are intended to measure domain specificity should clearly address content knowledge rather than the necessary learning skills in a domain.

Reiter-Palmon, Illies, Cross, Buboltz and Nimps (2009) buttressed an argument about domain specificity of creativity by showing that real-world problems require varying degrees of ability to solve. In their study, participants were presented one realistic everyday problem among the three problems to solve; complexity, involvement, and problem-based efficacy were varied among the problems. Problem solutions were evaluated by several criteria of creativity concerning quality of fluency and originality. The result showed that when the ability of the participants was controlled, different types of problems and criteria affected creativity. Such differences showed that even problems requiring a non-general trait of creative problem solving, creative abilities still did not resemble each other. Nevertheless, the conclusion is questionable because problems in a domain may require different levels of creative performance.

The inconclusive definition of creativity still needs investigation. This study will explore whether creativity is domain specific or general by requiring participants to apply divergent thinking skills and content knowledge simultaneously in a specific domain test and compare it with a creativity test intended to measure a general trait of creativity. This unique research design will provide a better understanding about the definition of creativity, especially for the nurturance of creativity in a classroom setting.

Since creativity is a complex construct, understanding personalities will also help in understanding the complex construct of creativity. Characteristics among creative scientists in specific areas, such as physics, chemistry, and biology, are rarely studied. Feist (2006) stated that one problem with the research on personality and scientific interest or achievement is that it is not specific to any domain of science, but rather covers scientists in general. Additionally, most of the studies on creative personality traits were conducted between 1950 and 1960. Also, the studies also employed a personality inventory, which was not specific to creativity traits.

Sternberg and Lubart (1993) contended that creative people share some attributes. Some well-known traits of creative people are originality, open-mindedness, imagination, curiosity, high motivation, intuition, a sense of humor, etc. (David, 2003). However, several studies have attempted to reveal the particular creative characteristics that are found in certain disciplines, such as the sciences, the arts, and music. Feist (1998) did a meta-analysis to verify whether creative traits varied across disciplines. According to his study, creative individuals in the arts and sciences did not share all of the same creative personality traits. For example, creative artists tended to be more emotionally unstable and displayed more coldness and obnoxiousness than group norms as compared to creative scientists.

Unique creative traits in particular disciplines should be further investigated to highlight the inclusion and fostering of such traits in the disciplines. Or, negative traits of the creative personality should be recognized to minimize their effects on creative performance.

In addition to considering creative personality, engagement in activities also accounts for individual creative performance. Both personality and activity engagement are related to an individual's level of creative development. Curricular, co-curricular, and extra-curricular experiences have considerable impact in increasing students' cognitive abilities, academic-related skills, and professional development (Kuh, 1995; Thiry, Laursen, and Hunter, 2001). The qualitative study from Thiry, Lauren, and Hunter (2001) in which they interviewed undergraduate students about their engagement in a wide range of activities in their disciplines including coursework, science projects within science courses, internships, and senior projects showed positive gains for participants who were more engaged in thinking and working like a scientist, becoming a professional, and having confidence in personal and professional development.

Several studies have also been done to explore degrees of involvement in activities as factors contributing to creativity. Davis and Belcher (1971) found a high correlation ( $r = .7$ , \*\*\*  $p < .005$ ) between the Alpha Biographical Inventory (ABI) academics and a test of creative process, the Remote Associates Test (RAT). Milgram and Hong (1999) studied 130 exceptional young adults whose scores were in the top 5% on tests of general intelligence and found out that there was a high correlation between out-of-school activities measured by self-reported items from the TAAI: Adolescent Form and the field of their adult vocation. Such correlation was also predictive of a higher level of work accomplishments when it was compared to their cohorts reporting an absence of out-of-school activities.

As a result, to give a comprehensive understanding of creativity, this study is attempting to provide evidence on whether creativity is domain general or specific. Creative abilities, personality, and involvement in activities among individuals in different science disciplines were taken into consideration to comprehend creative individuals' profiles.

### **Research Questions**

1. Do different levels of expertise and areas of science have an influence on the scores between the Creativity Test in Chemistry (CTC) and the Torrance Tests of Creative thinking, Verbal form (TTCT-V)?

2. Are there unique creative personalities of participants according to their areas of scientific study?

3. Are there identifiable and interpretable patterns of responses in the different groups of scientists by areas and levels of expertise in

- creative skills as measured by the two tests: CTC, and TTCT-V
- personality profiles as studied by The Gough Personality Scale
- the involvement in science activities leading to creativity as assessed by the Creative Activity and Accomplishment Check List from the rCAB

### **Method**

#### **Participants**

Participants were recipients of Development and Promotion of Science and Technology Talents Project (DPST) in Thailand. The total number of participants in this study was 219. There were 115 females (52.5%) and 104 males (47.5%). Their levels of expertise were reflected in their designation as high school students, undergraduates, or professionals, and their areas of

study were in physics, chemistry, or biology. Table 3.1 shows the demographic information of this group of participants based on levels of expertise and areas of science.

Table 3.1

*Demographic Data of Participants*

Levels of Expertise	Areas of Science			Total
	Physics	Chemistry	Biology	
High School	23	33	21	67
Undergraduate	28	33	19	88
Professionals	16	22	24	64
Total	77	80	62	219

### **Instruments**

There were four types of instruments used in this research. The sequence of the instruments was presented to participants similarly, beginning with the Creativity Test in Chemistry (CTC), the Verbal Torrance Test of Creative Thinking (TTCT-V), the Gough Personality Scale, and the Creative Activity and Accomplishment Check List (rCAB), respectively. Before performing on the instruments, participants were asked to fill in demographic information, namely gender, areas of science study, and levels of expertise.

The Creativity Test in Chemistry (CTC) (Sricharoen, 2016) was developed based upon the concept of the Construct Map method (Wilson, 2005). The test was used to measure creativity in a subject, chemistry, and was composed of 6 questions. The content of the test relied on chemistry knowledge but required test takers to provide multiple answers for each question. Participants had to apply divergent thinking skills, fluency, and flexibility to answer the

questions. The test has high EAP reliability for the two constructs of the tests: the quality of fluency and the association flexibility, which are .815 and .816, respectively. The Cronbach's alpha is .79.

The Verbal Torrance Test of Creative Thinking (TTCT-V) form B was used in this study. It is a standardized test that contains 6 activities and is scored for fluency, flexibility, and originality according to the manual (Torrance, 1990, 2008). Fluency is a count of the number of relevant ideas. Flexibility measures the number of different categories the ideas can be classified into, with more categories getting higher flexibility. Originality is a measure of the unusualness of the idea as compared to a sample in the standardization group. Reliability coefficients for various grades across two forms are .89-.92 (Torrance 1990, 2008). There is 50 years of extensive research that used the Torrance Tests of Creative Thinking, which indicated predictive validity between tests administered in childhood and adult creative achievements (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Runco, Millar, Acar, & Cramond, 2011). The Cronbach's Alpha for the test for this group of participants is .937.

The Gough Personality Scale (Gough, 1979; Gough & Heilbrun, 1965) is a self-assessment for creative characteristics. Originally, a test taker was required to check off creative adjectives corresponding to his/her characteristics. To study a more thorough understanding of creative characteristics, the scale was adjusted to be a 5-point rating scale for every trait of the characteristics. One adjective trait, which was dominant, was added in the scale, making the total number of adjectives 31 instead of 30 in the original scale. The Cronbach's alpha for the Scale is .977.

The Creative Activity and Accomplishment Check List from the rCAB, is employed in the study to assess the level of activities in science and mathematics. Test takers have to rate how

often they had been involved in such activities. The scale of involvement goes from never, once or twice, three to five times, to more than five times. It was put into a four-point Likert scale for scoring, ranging from one to four for never to more than five times. Question two, which asked participants about how often they had worked as an intern or with a mentor in the field of architecture, was excluded from the Scale because it was irrelevant to the five composite activity scores: general science, physics, chemistry, biology, and mathematics. The Cronbach's alpha for the whole test is .987. For each dimension as classified by a group of activities (general science, physics, chemistry, biology, and mathematics), the Cronbach's alpha is .941, .982, .973, .956, and .995, respectively.

All four instruments were in the English language. To ensure the validity of the translation for Thai participants, a back translation was used. The researcher translated all English instruments into the Thai language. Then, a Thai translator with a major in English helped translate the research from Thai into English. The back translation was finished when words, sentences, or the meanings were similar to the original English instruments. To check whether the meaning of the back translation remained intact, a native English speaker was involved in the process.

### **Procedure**

All the instruments were online questionnaires created with Qualtrics software. The questionnaires' links were directly sent to participants' email addresses. Participants received the CTC first. After finishing it, they received the package of the instruments containing the TTCT-V, the Gough Personality Scale, and the Creative Activity and Accomplishment Check List from the rCAB. The questionnaire contained demographic information about gender, levels of

expertise, and levels of study. Participants received a reminder every two weeks to complete the tasks that they had not finished.

The return rate of the DPST participants for the CTC was 78.5% due to the lengthy time for completion. The tracking process in the Qualtrics software showed that many participants started the test or filled out the test at a certain point but did not continue to completion. Among 219 participants who completed the CTC, the return rate for the questionnaire including the TTCT-V, the Gough Personality Scale, and the Creative Activity and Accomplishment Check List from the rCAB was 95.0%.

### **Scoring**

For the CTC, each response for each question was scored for two dimensions: the quality of fluency and the association flexibility. The highest score for each dimension in each question represents the scores for the quality of fluency and for the association flexibility of that particular question. Scoring for the quality of fluency and the association flexibility dimensions based on the construct map is shown in Table 3.2. Raw scores for the two dimensions of each individual were transformed into two kinds of scores: plausible values and Expected A Posteriori (EAP) scores. The transformation of scores was analyzed by Conquest 2.0. The five sets of plausible values came from the analysis of the unidimensional model in which the scores from the two dimensions were combined. There were two EAP scores generated from the two-dimensional model for each construct of the CTC: the quality of fluency and the association flexibility.

The five sets of plausible values ranged from -2.43 to 2.79 with the mean of 0.31 and the standard deviation of 0.96. The EAP scores took into account the scores for each dimension: the quality of fluency and the association flexibility. Ranges of EAP scores in the quality of fluency and the association flexibility were from -1.52 to 2.37 and -1.24 to 2.05, respectively. The values

of mean and standard deviation of EAP scores for the quality of fluency dimension and the association flexibility dimension were  $M = .33$ ,  $SD = .77$ , and  $M = .32$ ,  $SD = .65$ , respectively.

Table 3.2

*Scoring for the Quality of Fluency and the Association Flexibility Dimensions based on the Construct Map*

Level	Respondents	Scores
Quality of fluency		
Highly competent	Generating Responses different from what told in textbook or show evidence of knowledge beyond high school level.	3
Skillful	Responses demonstrate understandings of facts/concepts/ideas with supporting ideas.	2
Novice	Responses show simple facts/concepts/ideas with limited explanations.	1
No Fluency	Responses are incorrect or irrelevant to the question. Or, questions are simply found in chemistry textbooks.	0
Association flexibility		
Advanced Integrative	Responses integrate a concept beyond high school chemistry knowledge or combine concepts different from what told in chemistry textbooks. The combination of concepts is across disciplines.	4
Highly Integrative	Responses integrate a concept beyond high school chemistry knowledge or combine concepts different from what told in chemistry textbooks. The combination of concepts is not across disciplines.	3
Moderate Integrative	Responses show elaborative combinations of facts/concepts/knowledge related to a question.	2
Limited Integrative	Responses show at least a linkage concepts related to a question.	1
No Flexibility	There is no linkage of concepts shown in the responses.	0

For the TTCT-V, the responses were scored according to the Norms-Technical Manual (Torrance 1990, 2008), and the researcher was trained in a workshop to score this test. Scores for fluency, flexibility, and originality dimensions from six questions were combined to represent an individual's TTCT scores. Participants' scores ranged from 3 to 239 with the mean of 95.57 and the standard deviation of 42.15.

Scoring for the Gough Personality Scale was straightforward. Since the test used a 5-point Likert scale, each adjective trait in the Scale was assigned a score from 1 to 5, according to participants' ratings from the least to most representative of characteristics.

Items in the Creative Activity and Accomplishment Check List from the rCAB were computed to create composite activities scores for the five aspects. Total scores from a group of questions, 1–4, 5–14, 15–25, 2–37, and 38–48, represented participants' involvement in science activities: general science, physics, chemistry, biology, and mathematics, respectively.

### **Statistical Analysis**

For the first research question, the two-way ANOVA for CTC scores as the dependent variable and levels of expertise and areas of study as independent variables was done in an Excel spreadsheet. Since CTC scores for the first research question were plausible values, any analysis had to be undertaken five times with each relevant plausible value as variable (The Organization for Economic Co-operation and Development (OECD), 2012). The results were averaged, and then significance tests adjusting for variation between the five sets of results were computed. For the two-way ANOVA with total TTCT-V scores as the dependent variable, IBM SPSS Statistics 20 was used.

In response to the second research question, to explain personalities of this group of participants, Principal Component Analysis (PCA) was used to extract common factors among

personality traits in the Gough Personality Scale. From the preliminary analysis, three traits of personalities: sexy (item 27), submissive (item 28), and snobbish (item 29) were excluded from the analysis. The three items did not contribute factor loadings to any components and had a certain number of missing values. Eliminating those three items improved the interpretation of the factor analysis.

To answer the third research question, cluster analysis with K-Medoids (Park & Jun, 2009) was employed to understand the overall picture of creative skills in the CTC and the TTCT-V, personalities, and science activities contributing to creativity in this group of participants. The EAP scores for two dimensions: the quality of fluency and the quality of flexibility from the CTC and raw scores from the TTCT-V combining all dimensions were used in the analysis. Results from a previous PCA in the second research question were used. Also, combined scores for each activity type from Runco's Activity Check List was computed for this analysis. The R Project of Statistical Computing (R) and the Excel program were used for this analysis.

## **Results**

### **Research Question 1: The Effect of Levels of Expertise and Areas of Study on the Two Scores: CTC and TTCT-V**

Due to a low significant correlation between the two tests as dependent variables,  $r = .164$  ( $t = 2.451$ ,  $* p < .05$ ), a separate two-way ANOVA for each dependent variable was analyzed separately. To perform a MANOVA, the two dependent variables should be moderately correlated (Tabachnick & Fidell, 2001). The significant results from univariate analyses are shown in Table 3.3.

Table 3.3

*Significant Univariate Effects for Levels of Expertise and Scientific Areas*

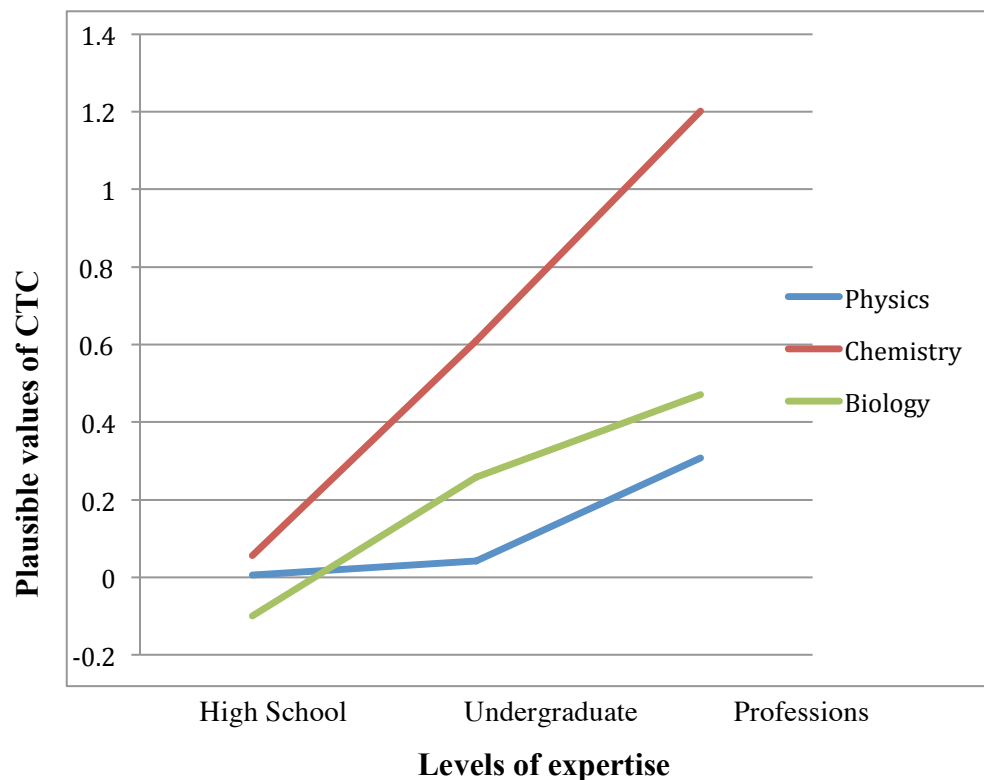
Dependent Variables	df	F	Independent Variables	Mean	SD	Lower Bound	Upper Bound
TTCT-V							
	2	4.700 **	Levels of expertise				
			High School	1.960	.027	1.907	2.013
			Undergraduate	1.859	.027	1.807	1.912
			Professions	1.965	.031	1.904	2.027
	2	.162	Scientific areas				
			Physics	1.927	.029	1.870	1.985
			Chemistry	1.940	.025	1.890	1.989
			Biology	1.918	.031	1.857	1.978
CTC							
			Levels of expertise				
	2	6.312*	High School	-.001	.892	-.035	.032
			Undergraduate	.328	.976	.291	.364
			Professions	.689	.858	.656	.721
	2	5.118*	Scientific areas				
			Physics	.094	.958	.058	.130
			Chemistry	.551	.891	.517	.584
			Biology	.221	.982	.184	.258
	4	4.217*	Expertise*areas	.314	.926	.279	.349

Note. df = degrees of freedom. expertise\*areas indicates the interaction between levels of study and scientific areas.  
 \*  $p < .05$ . \*\*  $p < .01$

Due to the heterogeneity of variance, TTCT-V's scores were transformed with log transformation. Log transformation is widely used to decrease the variability of data and make data closely distribute to normal distribution (Feng, Wang, Lu, Chen, He, Lu, & Tu, 2014). Since the interaction between the two independent variables, levels of expertise and areas of science, with the Verbal TTCT was not significant ( $F = .519, p < .05$ ), the main effects needed interpreting. Only the independent variable: levels of expertise was significant ( $F = 4.700, p < .05$ ), meaning that participants with different levels of expertise possessed varying abilities to earn scores on the Verbal TTCT. Scheffe's Post hoc Test showed that both high school students and professionals performed better than undergraduate students at  $* p < .05$ .

For the Creativity Test in Chemistry (CTC), the interaction between levels of expertise and areas of science was significant ( $F = 4.2171, * p < .05$ ). The main effects of levels of expertise and areas of science are not interpreted due to the significant interaction. The graph showing the interaction between the two independent variables and scores on the CTC was shown in Figure 3.1.

From the graph, it is clear that participants whose area was chemistry earned higher scores on the creativity test in chemistry at every level of study. The distinction of scores was obvious at higher levels of study according to the increasing gap between the graph of chemistry majors compared to other majors. The ability to perform on creativity test in chemistry for physics and biology majors was not distinctively different as seen by the narrow gap between the lines of the graph. Participants in biology major performed better on the test than physics major at undergraduate and professions levels. However, at high school level, students with an interest in physics performed better than biology major students.



*Figure 3.1.* The interaction between levels of expertise and areas of science on plausible values of CTC

### **Research Question 2: Personalities of Participants**

The number of participants completing the Gough Personality Scale was 208. Eight participants were excluded from the total number of participants (219) because their responses on the Scale were left blank. To perform principal component analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was examined. Its value was .749, close to 1, indicating that it was proper to run a PCA. A minimum Kaiser-Meyer-Olkin value of .5 is recommended for performing a PCA (Kaiser, 1974). The null hypothesis from Bartlett's Test of Sphericity was rejected, which indicated that the correlation matrix was not an identity matrix. The Scree Plot is shown in Figure 3.2.

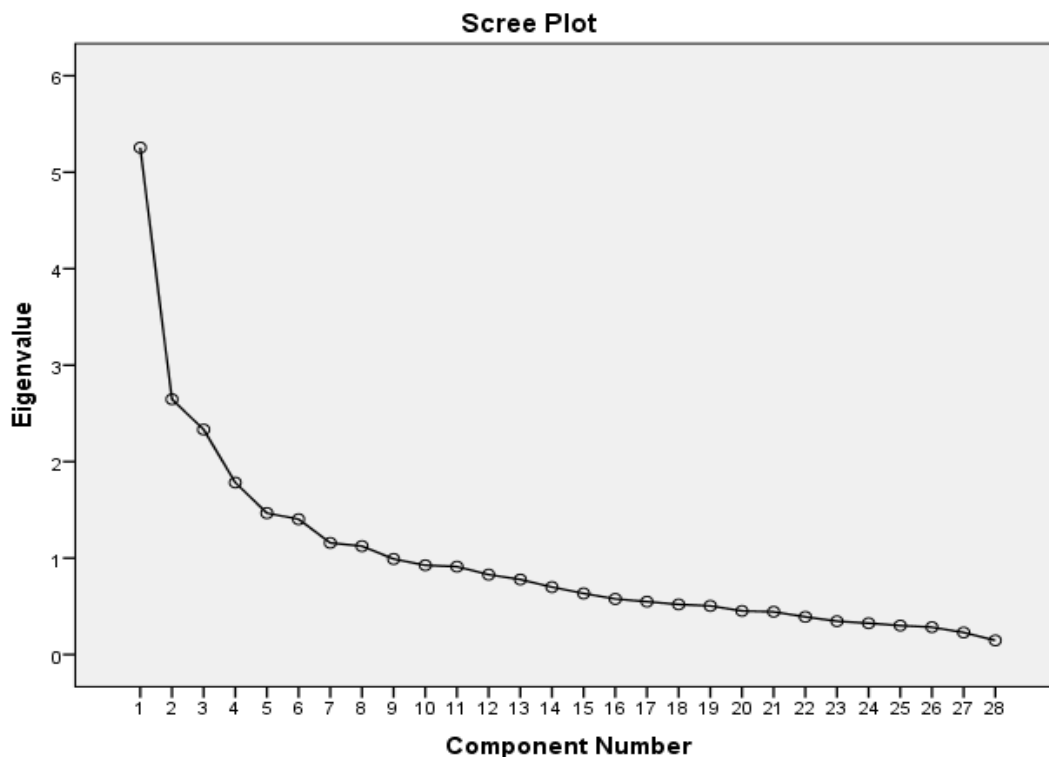


Figure 3.2. A Scree plot for the Gough Personality Scale results

PCA was performed based on the correlation matrix. Eigenvalues supported the retention of eight factors as the eigenvalues were 1.124, greater than 1. The total variance accounted for by the first factor was 61.311%, greater than seven factors which was 57.296% with Eigenvalue 1.157. Nevertheless, the Scree plot suggested seven or nine factors due to the way the line leveled off twice. Therefore, an eight-factor component was selected as it better accounted for the variance than seven factors and produced higher eigenvalues than nine factors. The traits of personality in accordance with the factors are shown at Table 3.4. The eight traits were useful to be employed in the cluster analysis in research question 3 as well. The small numbers of variables will help increase the power of the cluster analysis in accordance to the total number of participants, which were 208 in the research for question 3.

Table 3.4

*The Result of the Factor Analysis for the Gough Personality Scale*

	1	2	3	4	5	6	7	8
	Confidence	Insight	Sincerity	Creativity	Nonconformity	Skepticism	Humility	Narrow interests
2. Artificial	-.053	.059	<b>-.702</b>	-.159	.055	.27	-.122	.180
5. Confident	<b>.808</b>	.101	.126	.217	-.006	-.023	-.143	.004
6. Egotistical	<b>.668</b>	.125	-.391	-.004	-.080	.033	.026	.130
7. Commonplace	-.141	0.120	.048	.057	-.176	1.029	<b>.632</b>	.060
11. Conventional	.016	.122	.047	-.109	<b>-.681</b>	.286	.231	.035
12. Informal	-.061	.099	-.021	-.039	<b>.662</b>	.192	.29	-.163
14. Insightful	.036	<b>.673</b>	-.010	.148	.161	.225	-.052	.176
15. Suspicious	.094	.171	-.002	.124	.019	<b>.764</b>	-.085	-.119
16. Honest	.049	.199	<b>.712</b>	.018	-.023	.241	-.13	-.045
20. Inventive	.116	.093	.073	<b>.858</b>	.022	.066	.025	-.033
21. Original	.103	.127	.075	<b>.847</b>	.124	.059	.054	.021
22. Narrow interests	.035	.060	-.001	-.006	.103	-.03	.057	<b>.881</b>
23. Reflective	.033	<b>.750</b>	.123	.014	-.077	.02	.196	.016
24. Sincere	.12	.121	<b>.799</b>	.078	.049	-.044	.112	.098
26. Self-confident	<b>.831</b>	.027	.2	.142	-.007	-.05	-.072	-.093
30. Unconventional	.001	-.102	-.011	.045	<b>-.728</b>	.231	-.321	.131

Note: The method of extracting factors—the main components. Method of rotation—varimax with Kaiser normalization; rotation of convergence reached in 18 iterations. Bold was intended to show the strongest factor loadings, which make up the various factors.

### **Research Question 3: Comprehending Participants' Profiles based on Scores on Two Tests, Personality, and Science Activities Involvement.**

The same 208 participants from research question 2 were included in this analysis. Cluster analysis was aimed at classifying participants according to measured variables into a number of different groups in the way that similar subjects are placed in the same group. In other words, participants are heterogeneous among groups but homogeneous within a group. According to Silhouette's criteria (Rousseeuw, 1987), three clusters were suggested with the average value of Silhouette .4. Cluster membership is shown in Table 3.5.

Three clusters were labeled as the high ability group, the competent group, and the low ability group. The high ability group had higher means on both tests: the CTC and the TTCT-V than the competent group. The competent group had average mean on the TTCT-V but had a slightly lower mean on the CTC compared to the high-ability group. The low-ability group had low means on both tests.

From Table 3.6, when considering the number of participants in different areas of scientific study among the three groups, participants in chemistry were dominant in the high-ability group. In the competent group, although the number of participants in chemistry outweighed participants in physics and biology, the number of participants in chemistry was not distinctively dominant compared to the high-ability group in which the sum of participants in physics and biology was close to the number of participants solely in chemistry. In the low-ability group, most participants were from chemistry and physics with lower numbers of participants in biology.

Table 3.5

## Cluster Analysis Results with Scores on CTC, TTCT-V, Activity Checklist, and Personality Factors

Instruments	Cluster 1 (N=48)				Cluster 2 (N=95)				Cluster 3 (N=65)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Creativity Test in Chemistry												
Quality of fluency	-1.21	2.37	0.445	0.82	-1.03	2.00	0.42	0.72	-1.52	1.73	0.09	0.76
Association Flexibility	-0.98	2.05	0.42	0.69	-0.82	1.75	0.40	0.61	-1.24	1.51	0.12	0.65
TTCT-V												
Sum_TTCT	120	239	155.75	30.50	73.00	121.00	94.64	12.94	3.00	73.00	52.48	14.57
Activities relating to:												
General Science	5	16	10.73	3.19	0.00	16.00	10.24	3.76	0.00	16.00	9.25	3.86
Physics	10	31	13.81	4.42	0.00	40.00	14.15	6.92	1.00	32.00	13.74	6.62
Chemistry	10	42	17.31	8.14	11.00	44.00	17.02	8.03	11.00	39.00	16.57	7.06
Biology	12	47	16.83	7.89	0.00	37.00	17.22	7.40	9.00	48.00	15.37	6.99
Math	10	23	13.21	3.30	0.00	31.00	12.33	5.18	0.00	30.00	11.54	5.64
Personalities												
Confidence	3.95	11.54	8.05	1.58	2.31	10.87	7.70	1.60	2.31	11.54	7.77	1.76
Insight	2.85	7.12	4.96	0.92	2.85	7.12	5.05	0.87	2.85	7.12	4.88	0.92
Sincerity	3.13	6.85	5.02	0.93	0.76	6.85	4.89	1.29	0.93	7.56	4.92	1.48
Creativity	2.56	8.52	5.77	1.24	1.71	8.52	5.62	1.24	2.57	8.52	5.50	1.27
Nonconformity	-1.35	5.54	1.71	1.47	-0.67	6.27	2.16	1.24	0.01	6.27	2.05	1.39
Skepticism	0	3.82	2.55	0.73	0.76	3.82	2.74	0.54	0.00	3.82	2.46	0.72
Humility	1.26	3.16	2.27	0.45	0.63	3.16	2.20	0.58	0.00	3.16	2.20	0.57
Narrow interests	0	4.41	2.66	0.97	0.88	4.41	2.84	0.81	0.88	4.41	2.83	0.85

Note. Sum\_TTCT = combined scores of fluency, flexibility and originality on Torrance Tests of Creative Thinking, Verbal form.

Table 3.6

*The Number and Percentages of Participants in Different Scientific Areas of Study according to Cluster Groups*

Cluster groups	Scientific areas of study			Total
	Physics	Chemistry	Biology	
High ability group	13 (27.70%)	30 (31.60%)	23 (35.90%)	66 (32.00%)
Competent group	22 (46.80%)	38 (40.00%)	26 (40.6%)	86 (41.70%)
Low ability group	12 (25.50%)	27 (28.40%)	15 (23.40%)	54 (26.20%)
Total	47 (100.00%)	95 (100.00%)	64 (100.00%)	206 (100.00%)

The one-way ANOVA with tests scores as an dependent variable and clusters (1, 2, and 3) as the independent variable showed that there were significant differences among means of test scores among ability scores in the quality of fluency for the CTC ( $F = 4.453$ ,  $* p < .05$ ), ability scores in the quality of flexibility for the CTC ( $F = 4.483$ ,  $* p < .05$ ), and total scores from TTCT-V ( $F = 413.432$ ,  $* p < .05$ ). Post hoc tests were investigated to study mean differences. In the competent group (cluster 2), participants had higher scores in the quality of fluency and the quality of flexibility dimensions in the CTC than the low ability group (cluster 3). For TTCT-V scores, the high ability, cluster one had higher scores than the competent group and the low ability group; and the competent group earned higher scores compared to the low ability group.

The three groups did not have significant differences in mean among each activity category related to science. Among the three groups, all personality factors did not have significant mean differences, except for one personality factor: skepticism ( $F=3.807$ ,  $p < .05$ ). The post hoc suggested that competent group had a higher mean in this personality factor than the low ability group.

## Conclusions and Discussion

The correlation between scores from the Creativity Test in Chemistry (CTC) and Torrance Tests of Creative Thinking, Verbal form B (TTCT-V) was also significant but low, even though both tests required the same skills of creative thinking: divergent thinking. However, those who earned high scores on the creativity test in chemistry were more likely to have high scores on the TTCT-V, and vice versa. The result from the cluster analysis was consistent to show that participants with high scores on the CTC were more inclined to have high scores on the TTCT-V as participants in high scores from both tests were clustered in the same group both in the high ability and the competent group.

The CTC and the TTCT-V required participants to apply divergent thinking skills—fluency, flexibility, and originality—to complete the tests. However, they measured content embodied in creativity tests differently. The result from the 2-way ANOVA for CTC confirmed that those with majors or interests in chemistry performed better than other majors: physics and biology. Within the chemistry major, the higher the level, the higher scores participants earned. This finding provides evidence of domain specificity of creativity in chemistry, as knowledge influences the use of divergent thinking skills to provide quality responses in fluency and flexibility dimensions in the CTC.

For the TTCT-V, participants with different levels of expertise performed differently. Both high school and professional levels performed better than those at the university level. The age of university students in this research was around 19-21 years old. There have been several studies supporting the discontinuity of creativity development. One of the best well-known studies originated from Torrance (1967), which concluded that fourth grade students encountered a slump in creativity development due to social demands. In the Asian context, a study from

China indicated that Chinese students had a general decline from 10 to 16 years of age with large decreases from ages 12 to 14 (Yi, Hu, Plucker, & McWilliams, 2013).

Although these two studies did not show exact ages of slump in creativity close to the ages of the university students, the discontinuity of creativity development in the university level in Thailand needs to be taken into consideration. The optimal fit view of creative development (Barbot, Lubart, & Besancon, 2016) explained that individual differences in creativity outcomes result from the interaction among individual-level resources, such as cognitive levels, personality, and motivation, environmental influences, and the task characteristics. The change of variation among such factors contribute to peaks or slumps in creative performance. Consequently, the contributing factors for the drop of scores for Thai university students are tempting to study. Further research is needed to show whether this is a general condition or if it was just a fluke of this group of participants.

Additionally, the Principal Component Analysis (PCA) suggested eight personality factors for this group of participants, namely confidence, insight, sincerity, creativity, nonconformity, skepticism, humility, and narrow interests. These factors corresponded with several studies about characteristics among creative scientists in science majors, especially in physics, chemistry, and biology. Other researchers have found creative scientists to be confident (Pearce, 1968; Van Zeist & Kerr, 1954; Feist, 1998; Gregor, 1990), sensitive (Feist, 1998), original/initiative (Van Zeist & Kerr, 1954; Chambers, 1964), and less formal (Van Zeist & Kerr, 1954). These traits were in accordance with personality characteristics related to creative individuals in general, namely original and curious (Davis, 2013).

However, the participants in this study rated themselves as average for the humility factor from Table 3.4. Rudowicz & Yue (2002) studied creative personalities in the Asia-Pacific region

and found out that humbleness contributed to the factor loading .70 according to the Chinese personality dimensions of obedience or social acceptance. The humility factor may be a special trait of creative individuals in Asian countries, including Thailand.

Furthermore, from the study of personal explicit theories of creativity (Runco, Nemiro, & Walberg, 1998), people with the highest average rating for traits necessary for creative achievement did not rate narrow interests (Mean = 3.95, SD = 1.16) and wide interests (Mean = 3.82, SD = 1.03) differently. This trait of narrow or wide interest may not be an indicator of creative personalities. However, since this group of participants are gifted and had a specific focus in science, it may justify that narrow interest can be a creative trait for a certain population. Or, it may be a trait that facilitates their achievement.

The insignificant involvement in science activities contributing to creative achievement from the cluster analysis might also advocate the narrow interests trait. The high-ability group, the competent group, and the low-ability group were engaged in science activities similarly in every category of activities: general science, physics, chemistry, biology, and mathematics.

One other difference between groups was, the difference in the trait, skepticism between the competent and the low ability group. The competent group was significantly more skeptical than the low ability group. This trait should be fostered among the low creative group in science.

### **Implications**

The study found evidence of domain generality and specificity of creativity in chemistry. The CTC requires participants to apply divergent thinking to provide solutions regarding chemistry questions. Therefore, the result from the CTC showed evidence of domain generality in that divergent thinking is a skill that participants have to apply to in order to solve problems. Simultaneously, it is domain generality in that the skill is required to be used in the context of

chemistry. However, participants in chemistry outperformed those in other scientific study at all levels of expertise.

Simplistically considering, it was expected that participants in chemistry could perform better due to required knowledge of questions. However, the proportion of participants according to scientific study in cluster analysis suggested that there were still participants in chemistry clustered in the low-ability group. Even though all participants in this study were scientifically gifted, their creative performance varied. This varying degree of creative performance may be distinctively low among average or low-ability students in a classroom setting.

Such evidence implies the integration of creative thinking skills, namely divergent thinking in a content subject domain to support individuals' creativity in a classroom environment. Hong and Milgram (2010) argued that life experience (schooling and culture) strongly influences domain-specific creative thinking. The CTC provided the feasibility of applying this kind of test measuring both creative thinking skills and content knowledge to gain more information from individuals for further development in creativity.

This style of test can also be adopted in other domain subjects as well. Creative thinking skills like divergent thinking should be fostered, as supported by studies of successful transferability of other thinking skills: reasoning and critical thinking due to training (Lehman & Nisbett, 1990; Halpern, 1998). The assessment can determine whether the training is effective and how much further effort is required to perfect creative thinking skills. This assessment should be part of varied assessment strategies to capture different aspects of learning and achievement in science.

Because of the complexity of the creativity construct, personality traits, especially skepticism, should be fostered among science participants or average students during the course

of creativity development as well. Although science activity engagement among participants across different ability groups in this research did not contribute to any difference in creative performance, it is an unavoidable fact that such activities facilitate creativity to some extent. Providing scientifically gifted participants or average students with appropriate science activities will directly and indirectly support the development of creativity in individuals.

## CHAPTER 4

### DISCUSSION

To support the integration of creative thinking skills in the content of a subject, chemistry, two studies were conducted. The first study was the development of a creativity test in chemistry by measuring both creative skills and levels of knowledge according to the Construct Map method. The second study was designed to compare the profiles of participants when scores from the creativity test in chemistry, the Torrance Test of Creative Thinking, personality, and activities related to science were considered.

#### **Domain Generality and Specificity of Creativity**

The Creativity Test in Chemistry was developed to support the idea that creativity should be viewed as both domain general and domain specific. The test measured creative thinking skills: the quality of fluency and the association flexibility. Results from the first study confirmed that creativity in chemistry has two dimensions that can be measured: the quality of fluency and the association flexibility. This result corresponds with the structure of intellect (Guilford, 1959). This structure can be conceptualized as a three-dimensional cube in which intellectual operations, contents, and products form each of the dimensions. According to this view, thinking processes, including divergent thinking (fluency, flexibility, elaboration, and originality), are generalized abilities that could be applied to different categories of content in order to produce a variety of products. Accordingly, the skills of fluency and flexibility should be considered in understanding and developing creative thinking skills in chemistry.

The test measured not only creative thinking skills but also the levels of content in chemistry according to the construct map. The test had high reliability, and all items had good fit as the weighted fit mean square values fell within the acceptable range. Results from the test construction indicated that developing the test is feasible, capturing both creative skills and content mastery. More importantly, it is very important to promote this concept of test construction in a school setting. Based on the results, the significantly low correlation between scores from the Creativity Test in Chemistry (CTC) and Torrance Tests of Creative Thinking, Verbal form (TTCT-V) implied that even though the two tests measured similar creative thinking skills, they did not guarantee the transference of the skills from one test to the other.

However, the results of the cluster analysis showed that participants with high scores on the CTC were more inclined to obtain high scores in TTCT-V, as participants with high scores in both tests were clustered in the same groups: the high-ability group and the competent group. Moreover, results of the two-way ANOVA for the CTC confirmed that participants in areas of scientific study in chemistry performed better than those in other areas: physics and biology. In the chemistry major, the higher the education level, the higher the scores on the CTC the participants obtained. If creativity were not tied to content, all levels of study and majors should have performed similarly on the CTC. This result confirmed evidence of creativity in a domain because knowledge in chemistry influences the application of divergent thinking and the consequent provision of responses on CTC. Creative thinking skills are viewed as belonging to the general domain of creativity as they are the same skills that participants used to take the CTC and TTCT-V. However, they need to be fostered in a domain to help individuals produce creative performances. It can be concluded that creativity falls between domain generalization and domain specification (Kaufman & Bear, 1998; Simonton, 2007).

### **The Creativity Test in Chemistry**

The Creativity Test in Chemistry (CTC) provided a feasible way for a test to be implemented in a school setting to measure both creative thinking skills and a specific content. However, the test still required an ongoing process to improve its quality. The high correlation between the two dimensions of the quality of fluency and the association flexibility was a concern. Although the two-dimensional model showed a better significant fit than the unidimensional model in which the quality of fluency and the association flexibility scores were combined as one dimension, this problem should be fixed. The overlapping of scores in fluency and flexibility also happened in the Torrance Tests of Creative Thinking on figural form. As a result, Torrance, whose tests were based on the divergent thinking concept of Guilford, deleted the flexibility scoring on the figural test and added new norm-referenced scores to his test (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005). The Torrance Tests of Creative Thinking has been used and developed for more than 50 years. As a result, to improve the quality of this creativity test in chemistry, an ongoing process using the Four Building Blocks should be further implemented.

The scoring may need to be adjusted as the Wright map showed some overlapping in the categorical levels of scores. More items may be created and scored for one dimension rather than two, as this test's scoring showed. Item difficulties may be adjusted as the Wright map indicated that items were quite difficult vis-à-vis the participants' ability. Or new criteria for considering creative thinking skills in this test may be integrated.

Another interesting point to consider involved the differences in mean performance when genders, levels of study, and scientific areas of study were taken into account. Participants with different genders, levels of study, and areas of science had particular responses to all the

questions. For example, undergraduate students had trouble performing the quality of fluency ideas on questions two and four, while professionals found it difficult to form the quality of fluency ideas on questions five and six. These particular responses could be the result of unfamiliarity to the style of tests. The varying preferences of the participants to form fluent or flexible ideas could also be a cause. The continued use of this test could provide a clear pattern of responses for a certain group. Careful consideration when giving the test to a group had to be taken into account for the interpretation of scores.

Furthermore, applying this type of test in a school environment was challenging. The CTC consisted of open-ended questions requiring multiple possible responses for each question. The style of the test was new in this domain subject, chemistry. Some participants liked this testing style as it allowed them to connect and form unique ideas; others thought that the questions were difficult and too imaginative. High school students were more likely to favor this test than undergraduates and professionals. From my viewpoint, integrating this style of questions is interesting to measure creative thinking skills and levels of knowledge acquisition in a domain. Using this style of test to capture students' creativity and knowledge in several topics of subjects is possible. According to a systematic review (Thys, Sabbe, & Hert, 2013), the most frequently used creativity measures could be categorized into four groups: the creative person, the creative process, the creative products, and the creative place/press. All the tests shown in this study were content-free. As a result, the promotion of using creativity in a domain subject should be employed.

It would be interesting to see if using creative questions in content areas with high school students would encourage more creative thinking, motivation, and in-depth learning in the content areas. Further research should examine this possibility.

### **The Individuals' Creativity Profiles**

It was interesting to note that for the TTCT-V, participants from different levels of study performed differently. Both the high school and the professional levels performed better than the university level. The ages of the university students in this research were 19–21 years old. Several studies supported the discontinuity of creativity development. One of the most well-known studies was that of Torrance (1967), which concluded that fourth-grade students encountered a slump in creativity development because of social demands. In Asia, a study in China indicated that Chinese students had a general decline in creativity from 10 to 16 years of age with large decreases from 12 to 14 (Yi, Hu, Plucker, & McWilliams, 2013).

Although these two studies did not show the exact ages of slump in creativity close to the ages of university students, the discontinuity of creativity development in the university level in Thailand needs to be taken into consideration. The optimal fit view of creative development (Barbot, Lubart, & Besancon, 2016) explains that individual differences in creativity outcomes result from the interaction of individual-level resources, such as cognitive levels, personality, motivation, environmental influences, and task characteristics. Changes in variation among such factors contributed to peaks or slumps in creative performance. The slump in creativity among members of the university student group should not lead to a rash conclusion, but the contributing factors of the drop in creativity scores among Thai university students would be worth studying.

I have posited earlier that individual differences in creativity outcomes result from the interaction between individual-level resources and task-specific demands. This “optimal fit” view translates easily from a developmental perspective: performance outcomes in a given creative outlet depend on specific creative task characteristics and the (asynchronous)

development of person-level characteristics (e.g., DT and other cognitive factors, personality, and motivational and emotional characteristics). At different points in time, the resulting multivariate profile of person-level resources is more or less in line with particular task requirements, leading to outcomes of variable creativity over time.

Additionally, the Principal Component Analysis (PCA) suggests eight factors for this group of participants, namely, confidence, insight, sincerity, creativity, nonconformity, skepticism, humility, and narrow interests. These factors correspond with several studies of characteristics of creative scientists in science majors, especially in physics, chemistry, and biology. Creative scientists are confident (Van Zeist & Kerr, 1954; Feist, 1998), sensitive (Feist, 1998), original/initiative oriented (Van Zeist & Kerr, 1954; Chambers, 1964), and informal (Van Zeist & Kerr, 1954). These traits correspond with the personality characteristics of creative individuals in general, that is, originality and curiosity (Davis, 2013).

However, the participants of this study rated themselves to be not different from the general public. This factor can be viewed as humility. Rudowicz and Yue (2002) studied creative personalities in the Asia-Pacific region and found out that humility contributes with a factor loading of .70, according to the Chinese personality obedience or social acceptance dimension. The generality factor could be a special trait of creative individuals in Asian countries, including Thailand. Furthermore, based on the study of personally explicit theories of creativity, people with the highest average rating manifest traits necessary for creative achievement.

The traits of narrow and wide interests were not rated differently (Runco, Nemiro, & Walberg, 1998). The trait of narrow or wide interest might not be indicative of creative personalities in this population. Since these participants were gifted and had a specific focus on science, narrow interest could be a creative trait for this population. Insignificant involvement

in scientific activities contributing to creative achievement based on the cluster analysis could also advocate the narrow-interest trait. The high-ability group and the competent group were not differentially engaged in scientific activities as compared to the low-ability group. Nevertheless, there was a difference in the trait of skepticism between the competent and the low-ability group. This trait should be fostered among members of the low-creativity group in science.

### **Implications**

This research advocates the nurturance of divergent thinking skills in a domain. Although creative thinking skills are not equivalent to divergent thinking skills, the facilitation of fluency, flexibility, and originality in a curriculum helps foster creativity. Since the transferability of skills can happen as a result of training (Lehman & Nisbett, 1990; Halpern, 1998), it is vital to integrate divergent thinking in a content domain. Training in creative thinking skills, like that in divergent thinking skills, should be incorporated in inquiry and assessed in such a way as to strengthen creative performance in a domain.

Creative thinking processes which emphasize individuals' thinking process and that do not rely on any domain knowledge (Wallach, 1926; Torrance, 1966; and Sternberg, 1985) can be applied to nurture individuals' creativity, especially in science inquiry. As inquiry focuses on developing students' scientific skills by bringing students to engagement, exploration, explanation, elaboration, and evaluation, creative processes support strategic thinking. Such divergent thinking or ideation can be used along with inquiry to help students generate several possibilities, alternatives, and solutions through the process of inquiry. For example, in an engagement process, a teacher may ask students to generate many chemical products that they encounter in daily life. The teacher may ask them to group the products and elaborate the criteria they use for grouping. He or she may then point out how each method of grouping them is

unique. It is not necessary to employ all inquiry skills within one lesson. The teacher should use good judgment to select inquiry skills with divergent thinking skills that will help students learn meaningfully and make the most of their learning.

Teaching and learning in science or chemistry happen in two environments: in the classroom and in the laboratory. Inquiry and creative thinking can be integrated in these two environments in order to foster students' achievement and creativity. There are several studies using creative teaching to promote both inquiry and divergent thinking in chemistry. Some studies focus on the employment of contexts (Pilot & Bulte, 2006; Nieswandt, 2007), posing questions or group discussions (Wood, 2006), problem categorization (Zikovelis & Tsaparis, 2006), visualization methods (Coll & Treagust, 2007; Harrison, 1996), metaphors (Last, 1993; Miller, 1996), and inquiry (Farrell, 1999; Hofstein, Navon, Kipins, & Mamlok-Naaman, 2005; Luft, 2004). In a unit or lesson of study, teachers can select teaching methods that are appropriate for content knowledge and use inquiry and divergent thinking skills to help the students learn meaningfully and creatively. For example, in a laboratory, a teacher may encourage students to discuss why the lab results did not turn out as expected and ask them to fluently explore possible explanations for this.

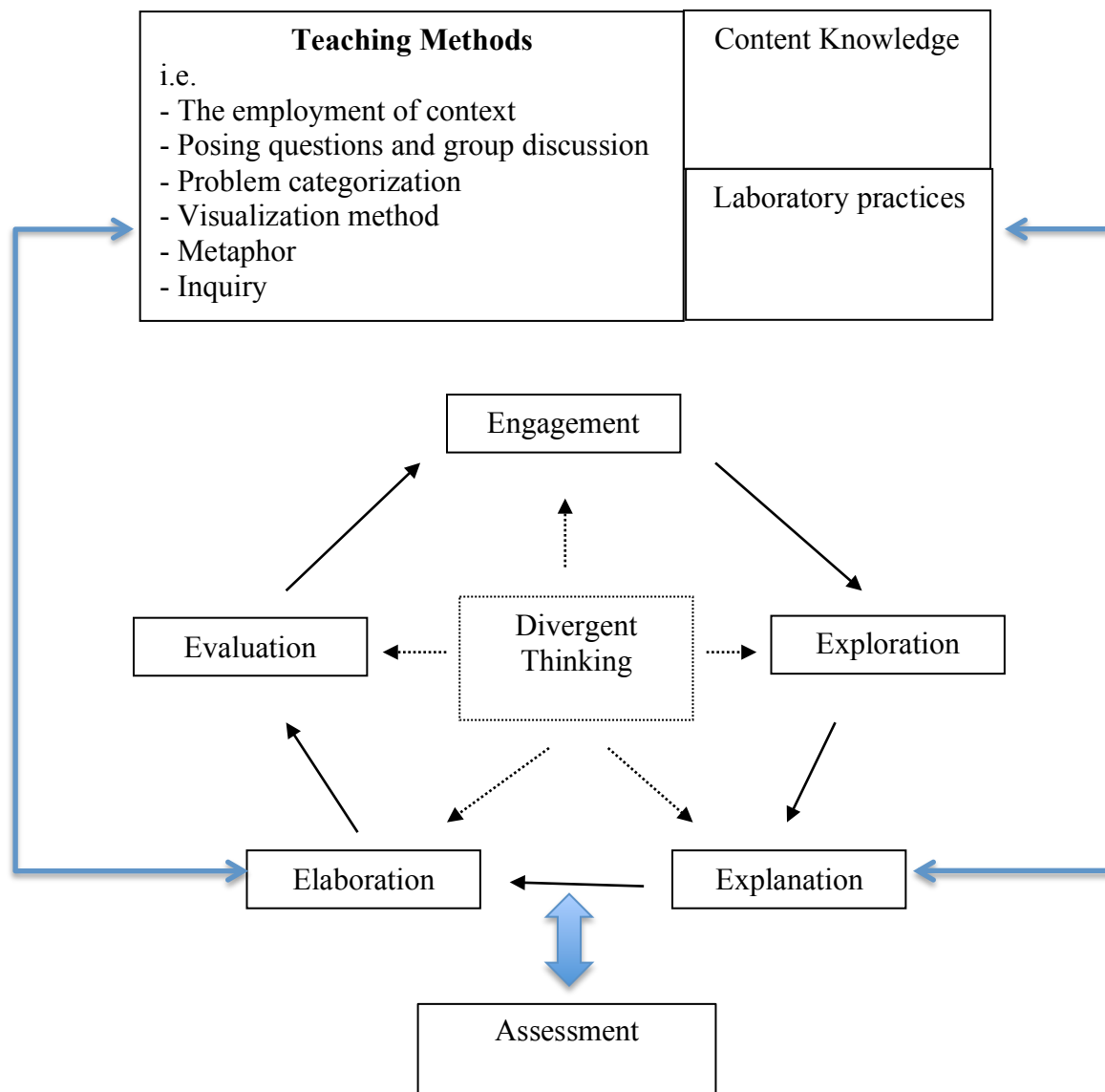
As the mastery of content through inquiry as well as creative thinking is incorporated in chemistry learning, teachers should create assessment that reveals such abilities. They may employ multiple alternative assessments to measure their students' abilities in chemistry and creativity. A test, such as the CTC, should be created for a specific lesson in order to capture such abilities. Moreover, teachers should use the results from the assessment as a formative approach to further develop their students' abilities and as a summative approach to help their students master defined learning objectives at the highest levels possible.

Figure 4.1 illustrates how the nurturance of creative thinking skills can be fostered in chemistry to help students perform more creatively. Divergent thinking can be incorporated in inquiry along with teaching methods for content knowledge and laboratory practices. Then, assessment in formative and summative forms reflects an individual's performance at defined creative levels. Such reflection is used to strengthen knowledge and creativity skills simultaneously, helping students excel in chemistry. A type of test, for example, the CTC may serve as a formative and summative assessment to reveal the reflection in question.

Skepticism or other positive personality traits can be fostered through learning and teaching in chemistry. For instance, teachers may ask students to figure out whether chemical equations are correctly balanced and encourage them to explain their associated thoughts. Such a teaching activity would strengthen students' curiosity as well as their confidence in their knowledge. Relevant science activities can also help foster students' traits and creativity. Students should be introduced to science activities to help them deepen their knowledge and cognitive skills in chemistry (Kuh, 1995; Thiry, Laursen, & Hunter, 2001).

### **Limitations**

The Creativity Test in Chemistry (CTC) needs improvement in order to better capture individuals' divergent thinking skills and content knowledge in chemistry. The two-dimensional model provides sound support for the assertion that the test consists of two constructs: the quality of fluency and the association flexibility. However, the high correlation between the two constructs may raise reservations regarding whether they measure the same creative thinking skills.



*Figure 4.1.* The incorporation of divergent thinking in teaching methods for developing creative performance in chemistry by using the assessment

Since the development of the quality of the CTC is an ongoing process, the interpretation of test results should not be the sole criterion for determining whether a person is creative in chemistry. Due to the lack of specific content for each unit of study in chemistry, the CTC may

not be used to make generalizations regarding creativity in chemistry. Rather, it is encouraging to use the test results to improve a person's creativity according to the two construct maps when chemistry content knowledge is applicable to a target population. For example, CTC may not be appropriate to use as a criterion for determining the creativity levels of tenth graders as it covers some content that they have not learned. Nevertheless, the test may be used as a formative assessment to direct teachers' planning of appropriate methods for developing students' content and creative thinking in chemistry. Such planning should aim at encouraging students to reach the high levels of the two construct maps once they acquire the knowledge.

### **Future Research**

It is encouraging to continue developing the Creativity Test in Chemistry (CTC) in such a way that the correlation between the two constructs is reduced and they represent divergent thinking skills and content knowledge in chemistry more effectively. Moreover, the CTC was developed based on general content in chemistry to improve the acquisition of information regarding the development of divergent thinking along with chemistry knowledge. Hence, a particular test for a unit or learning objective should be created. An assessment of divergent thinking skills as well as general and specific content in a domain should be extended to other subject domains; it should not be limited to chemistry.

As a finding suggested a slump in creativity for participants at the university level, a study should be conducted to determine whether creative performance really descends at that level. The factors that contribute to such a descent should also be studied for the thorough understanding of such phenomena. Moreover, this kind of study should be implemented among high school students and professionals as there is still a lack of research explaining creativity in the Thai population.

Moreover, professionals' personalities should be investigated more thoroughly. The study of personalities should not be limited to a questionnaire format. An extensive interview may be important for determining the extent to which some professionals are more creative than their cohorts. From observation and a personal conversation with some professionals, only some of them have the capacity to be innovative in the absence of facilities or equipment. In addition to fostering skepticism, a trait found to vary between the competent and the low ability groups in this study, there may be other personality traits that students could learn from creative professionals to facilitate the more effective nurturance of creativity among the students.

Involvement in science activities did not vary among the three groups of participants (the low-ability, competent, and high-ability groups). However, it would be vital to learn, in detail, how such involvement could facilitate creativity among scientifically gifted participants. It may be useful to know the extent to which various activities support creativity among some certain participants. Alternatively, it may be useful to know which activities are necessary but inadequate. For example, interviewing professionals may help create more appropriate activities for fostering creative innovation among students, or a survey of high school students or university students may help educators determine which activities they need to develop their creativity.

Last, systematic research should be conducted to determine how creative thinking skills can be applied with inquiry to support students' construction of knowledge and their creativity. It would be challenging to apply the model presented in Figure 4.1 in a concrete manner that would help students learn chemistry meaningfully and creatively. The model should not be limited to chemistry. It can be a model for developing the acquisition of knowledge and that of creative thinking skills in other subjects.

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## APPENDICES

## APPENDIX A

### TABLE OF RESEARCH QUESTIONS AND ANALYSES

The main purpose of the two studies from the second and third chapters is to support the nurturance of creativity in domain specificity and generality. The second chapter emphasized how creativity can be assessed in the specific domain of chemistry. The Creativity Test in Chemistry (CTC) was thus developed based on the Construct Map. The third chapter provided evidence to argue whether creativity was domain generality or specificity. Accordingly, participants' scores on CTC from the second chapter was used to compare with the participants' scores on Torrance Tests of Creative Thinking, Verbal form (TTCT-V), was meant as a way to assess creativity as domain generality.

In addition to the two tests, CTC and TTCT-V, participants' personalities, and the intensity of how they are involved in science is considered in chapter 3. Such inclusion provided more information about creative individuals as the result of the complexity of the creativity for further development.

Chapters	Research questions	Analyses
2	2.1 Does creativity have two constructs, the quality of fluency and the association flexibility, as measured by the CTC?	<p>The software, Conquest 2.0, was used to analyze data according to the Rasch Model.</p> <p>The analysis was intended to verify whether the measure of creativity on the CTC has two constructs: the quality of fluency and the association flexibility. In order to verify a unidimensional model, scores from the two dimensions were combined and were tested. Then, the two-dimensional model, in which responses were scored for two dimensions: the quality of fluency and the association flexibility was analyzed using MRCML model by Conquest 2.0 as well. The statistical results from deviance, AIC, and BIC from the two models: the unidimensional and the two-dimensional models were compared.</p> <p>Since the two-dimensional model had better fit than the unidimensional model, DDA technique was run, thus allowing the comparison of estimated students' ability across the two constructs.</p>

Chapters	Research questions	Analyses
2	2.2 What is the quality of the CTC in terms of reliability and validity?	<p>By using the DDA technique, results from the two-dimensional model provided reliability.</p> <p>The fitted model of the two-dimensional model suggested an internal consistency of the constructs of creativity as measured by the CTC.</p> <p>DIF technique was used to determine if students' abilities vary when taking into consideration their gender, levels of expertise, and their specific area of scientific studies. DIF was run from the unidimensional model.</p> <p>Information from DIF supported <i>validity based on external relations</i>.</p>
3	3.1 Do different levels of expertise and areas of science have an influence on the scores between the Creativity Test in Chemistry (CTC) and the Torrance Tests of Creative thinking, Verbal form (TTCT-V)?	<p>Due to the low correlation between the score from the CTC and that of TTCT-V, a separate 2-way ANOVA for each dependent variable, scores from both CTC and TTCT-V were run.</p> <p>The two independent variables for each dependent variables were levels of expertise and areas of science.</p>

Chapters	Research questions	Analyses
3	<p>3.2 Are there unique creative personalities of participants according to their areas of scientific study?</p>	<p>All 31 items on the Gough Personality Scale were analyzed by Principal Component analysis. The analysis provided information about how items could be grouped for meaningful interpretations. The grouping of items was important in reducing the number of variables used in the research question 3.3.</p>
	<p>3.3 Are there identifiable and interpretable patterns of responses in the different groups of scientists by areas and levels of expertise in creative skills, personality, and the involvement in science activities?</p>	<p>Cluster analysis was used to study the pattern of characteristics of DPST participants in relation to creative abilities as measured by CTC and TTCT-V, personalities, and involvement in science activities. Within rCAB, the Creative Activity and Accomplishment Check List has a list of 48 items that quantifies the participants' involvement in science activities were combined into five disciplines: general science, physics, chemistry, biology, and math. This reduced the number of variables for cluster analysis.</p>

## APPENDIX B

## CREATIVITY TEST IN CHEMISTRY (CTC)

**Creativity in Chemistry****A guideline to Creativity in Chemistry**

- This creativity in chemistry questionnaire consists of **6 items**. You have **10 minutes** to complete each question. If you cannot finish a question within the time limit, a new question will pop up. You cannot go back to correct answers from a previous question whether you finish it or not.
- This test intends to measure the 3 main traits as follows:
  1. Fluency: The ability to generate as many answers as possible and your answers show your knowledge in chemistry.
  2. Flexibility: The ability to give answers that can be viewed in several aspects/groups and your answers belonging to those aspects/groups also reflect your knowledge in chemistry.
  3. Originality: The ability to think differently than the mainstream as well as demonstrating your knowledge in chemistry.
- Guideline to answer this test
  - Since this test will be scored according to the traits mentioned above, you should try your best to provide as many answers as possible, different groups of answers, including original answers that no one might think of.
  - There are no right or wrong responses as long as there is a possibility that your responses will work.
  - You may give examples or specific situations to answer or clarify your responses.

**Good Luck on our exam.**

### Creativity Test in Chemistry (CTC)

1. If you had a chance to meet with a well-known scientist(s) from the past or present, what observations or questions regarding their knowledge of chemistry would you like to ask them? Why would you ask them that question? What do you expect you would do with their response to the questions? Would the response help you, your family, your country, or all of humanity?
2. In an experiment, if your chemical reactions did not come out as you expected, what would you speculate could be the causes of the unexpected results regarding the reactions? What would you do to confirm that your ideas were correct?
3. If you have three types of clear liquids with no color, how would you identify the properties and chemical nature of those liquids? Describe the steps you would take, and discuss the possible outcomes.
4. Nowadays, plastics are widely used. How can you use your knowledge of *chemical properties* or *reactions* to improve the qualities of the plastics we use in different forms? How could plastic products be more useful or appropriate for our utilization?
5. From the chemical properties you have learned, do you think there are atoms or molecules that could be substituted for one another in order to study, test, or create chemical reactions? If so, why? What could you use this knowledge for?
6. Suppose all the atomic numbers of atoms on the periodic table increased by 1, how would that affect the knowledge you have learned in chemistry? What interesting things could you do with the new knowledge?

## APPENDIX C

## TORRANCE TESTS OF CREATIVE THINKING-VERBAL FORM B

## Activities 1-3 Ask-And-Guess

The first three activities will be based on the drawing below. These activities will give you a chance to see how good you are at asking questions to find out things that you don't know and in making guesses about possible causes and consequences of happenings. Look at the picture. What is happening? What can you tell for sure? What do you need to know to understand what is happening, what caused it to happen and what will be the result.



Activity 1. Asking. On this page, write out all of the questions you can think of about the picture on the page opposite this one. Ask all of the questions you would need to ask to know for sure what is happening. Do not ask questions which can be answered just by looking at the drawing. You can continue to look back at the drawing as much as you want to.

Activity 2. Guessing Causes: In the space below, list as many possible causes as you can of the action shown in the picture on page 2. You may use things that might have happened just before the things that are happening in the picture, or something that happened a long time ago that made these things happen. Make as many guesses as you can. Don't afraid to guess.

Activity 3. Guessing Consequences: In the spaces below, list as many possibilities as you can of what might happen as a result of what is talking place in the picture on page 2. You may use things that might happen right afterwards or things that might happen as a result long afterwards in the future. Make as many guesses as you can. Don't be afraid to guess.

Activity 4. Product Improvement: In the middle of this page is a sketch of a stuffed toy monkey of the kind you can buy in most dime stores for about one to two dollars. It is about six inches tall and weighs about six ounces. In the spaces on this page and the next one, list the cleverest, most interesting and unusual ways you can think of for changing this toy monkey so that children will have more fun playing with it. Do not worry about how much the change would cost. Think only about what would make it more fun to play with as a toy.

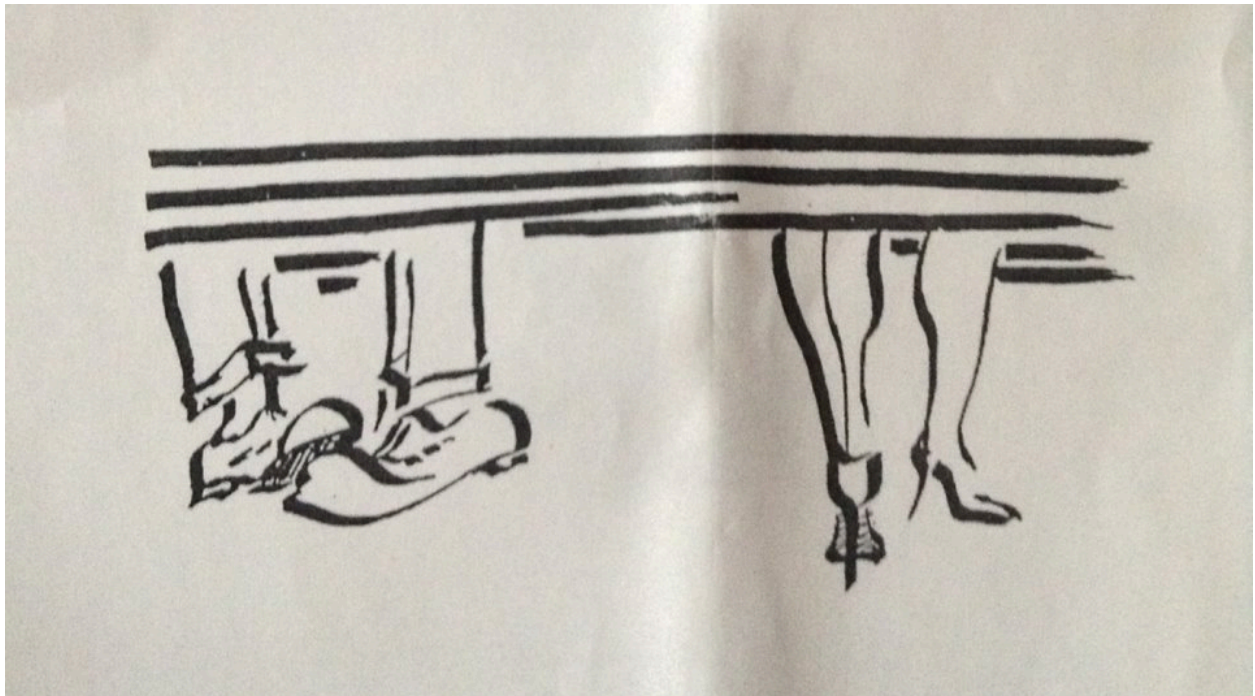


Activity 5: Unusual uses (Tin Cans). Most people throw their tin cans away, but they have thousands of interesting and unusual uses. In the spaces below and on the next page, list as many of these interesting and unusual uses as you can think of. Do not limit yourself to any one size of can. You may use as many cans as you like. Do not limit yourself to the uses you have seen or heard about; think about as many possible new uses as you can.

Activity 7: Just Suppose. You will now be given an improbable situation—one that will probably never happen. You will have to just suppose that it has happened. This will give you a chance to use your imagination to think out all of the other exciting things that would happen IF this improbable situation were to come true.

In your imagination, just suppose that the situation described were to happen. THEN think of all of the other things that would happen because of it. In other words, what would be the consequences? Make as many guesses as you can.

The improbable situation—JUST SUPPOSE a great fog were to fall over the earth and all we could see of people would be their feet. What would happen? How would this change life on earth? List your ideas on guesses on the next page.



## APPENDIX D

## GOUGH PERSONALITY SCALE

Please rate the following characteristics representing your personalities according to the Likert Scale

	The least representative	Little representative	Moderate representative	More representative	Most representative
Capable					
Artificial					
Clever					
Cautious					
Confident					
Egotistical					
Commonplace					
Humorous					
Conservative					
Individualistic					
Conventional					
Informal					
Dissatisfied					
Insightful					
Suspicious					
Honest					
Intelligent					
Well-mannered					
Wide interests					

	The least representative	Little representative	Moderate representative	More representative	Most representative
Inventive					
Original					
Narrow interests					
Reflective					
Sincere					
Resourceful					
Self-confident					
Sexy					
Submissive					
Snobbish					
Unconventional					
Dominant					

## APPENDIX E

## ACTIVITY CHECK LIST

**ACTIVITY CHECK LIST**

Part of the *Runco Creativity Assessment Battery* (rCAB)<sup>©</sup> 2011.

THIS IS AN INVENTORY, NOT A TEST. THE INVENTORY IS SIMPLY A LIST OF ACTIVITIES AND ACCOMPLISHMENTS IN VARIOUS FIELDS OF STUDY. YOUR TASK IS TO CIRCLE THE RESPONSE (a-e) THAT BEST DESCRIBES THE FREQUENCY OF THE ACTIVITY. WE WOULD LIKE TO KNOW, HOW OFTEN HAVE YOU DONE EACH OF THE ACTIVITIES? BE SURE TO ANSWER EVERY QUESTION, AND DON'T WORRY ABOUT DUPLICATE OR SIMILAR ITEMS.

VERY IMPORTANTLY, EXCLUDE ACTIVITIES AND ACCOMPLISHMENTS THAT WERE REQUIRED. DO NOT COUNT ASSIGNMENTS. FOCUS ON "EXTRACURRICULAR" ACTIVITIES AND ACCOMPLISHMENTS. THANK YOU.

HOW MANY TIMES, OR HOW OFTEN, HAVE YOU ....

1. Solved statistical/mathematical problems with a computer

A	B	C	D
Never	Once or twice	3-5 times	More than 5 times

2. Set up own experimental conditions or laboratory

A	B	C	D
Never	Once or twice	3-5 times	More than 5 times

3. Constructed something that required technical knowledge, such as a radio, telescope, or other scientific apparatus

A	B	C	D
Never	Once or twice	3-5 times	More than 5 times

4. Worked as a laboratory assistant
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
5. Presented an original plan, design, or paper on PHYSICS to a professional group or at a conference?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
6. Had a plan, design, or paper published in a professional PHYSICS journal or outlet?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
7. Designed an experiment to test a hypothesis about PHYSICS principles?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
8. Used 3D software to capture an original PHYSICS idea?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
9. Participated in a PHYSICS club or organization?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
10. Won an award for a PHYSICS paper or project?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
11. Worked as an intern or with a mentor in the field of PHYSICS?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |

12. Had your original research or your ideas about PHYSICS cited by others?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
13. Offered an original solution to an PHYSICS problem to others working in that field?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
14. Submitted a paper or proposal to a PHYSICS competition?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
15. Presented an original paper on CHEMISTRY to a professional group or at a conference?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
16. Had a plan, design, or paper published in a professional CHEMISTRY journal or outlet?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
17. Designed an experiment to test a hypothesis about CHEMISTRY principles?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
18. Used 3D software to capture or express an original idea about CHEMISTRY?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
19. Participated in an CHEMISTRY club or organization?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |

20. Won an award for an CHEMISTRY plan, design, technique, or paper
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
21. Worked as an intern or with a mentor in the field of CHEMISTRY?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
22. Had your original research or your ideas about CHEMISTRY cited by others?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
23. Offered an original solution to an CHEMISTRY problem to others working in that field?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
24. Submitted a proposal to an CHEMISTRY competition?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
25. Received praise or public appreciation for solving a problem in your community by applying CHEMISTRY?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
26. Presented an original theorem or paper on MATHEMATICS to a professional group or at a conference?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
27. Had a theorem or paper published in a professional MATHEMATICS journal?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |

28. Designed an experiment to test a hypothesis about MATHEMATICS?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
29. Used 3D software to capture an original MATHEMATICAL theorem or idea?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
30. Participated in a MATHEMATICS club or organization?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
31. Won an award for a MATHEMATICS paper or theorem?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
32. Worked as an intern or with a mentor in the field of MATHEMATICS?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
33. Received public praise for applying MATHEMATICS to a problem or issue in your community?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
34. Had your original research or your ideas about MATHEMATICS cited by others?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
35. Offered an original solution to a MATHEMATICAL problem to others working in that field?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |

36. Submitted a paper or abstract to a MATHEMATICAL competition?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
37. Presented an original plan, design, or paper on Biology to a professional group or at a conference?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
38. Had a plan, design, or paper published in a professional Biology journal?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
39. Designed an experiment to test a hypothesis about Biology?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
40. Used 3D software to capture an idea from the Biological Sciences?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
41. Participated in an Biology club or organization?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
42. Won an award for a Biology or paper or study?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
43. Worked as an intern or with a mentor in any of the Biological Sciences?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |

44. Constructed a model to capture an idea from the Biological Sciences?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
45. Had your original research or your ideas about Biology cited by others?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
46. Offered an original solution to a Biology problem to others working in that field?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
47. Submitted a proposal to a competition in the Biological Sciences?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |
48. Received public praise of any sort for solving a problem in your community by applying principles from the Biological sciences?
- |       |               |           |                   |
|-------|---------------|-----------|-------------------|
| A     | B             | C         | D                 |
| Never | Once or twice | 3-5 times | More than 5 times |