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ABSTRACT

This study explores the learner dimension in learning biological science topics in five elementary school classrooms instructed by different teachers using a common course of study and outcome measures. Specifically, the study addressed the associations among conceptual, metacognitive, cognitive, stylistic, and affective characteristics and science achievement. Results of the cognitive learning style assessment suggests that the students were primarily field-dependent. In terms of personality-based learning style, the students were described primarily as either sensing-feeling or intuition-feeling learners with differences between males and females. No clear pattern of relationships was found between cognitive-based learning style and personality-based learning style. Findings suggest that students with high metacognitive awareness and metacognitive self-management made greater gains in conceptual knowledge than did those with low metacognitive awareness and self-management. Cognitive learning styles were found to correlate strongly with prior conceptual knowledge, metacognitive measures, and science achievement. Contains 52 references. (JRH)

Relationships among P ior Conceptual Knowledge, Metacognitive Awareness, Metacognitive Self-Management, Cognitive Style, Perception-Judgment Style, Attitude toward School Science, Self-Regulation, and Science Achievement in Grade 6-7 Students

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Introduction

The interactive-constructive model of learning considers both the similarities and differences in perception and processing of diverse information sources and how prior knowledge, task, concurrent experience, language, metacognition, and context influence these situations. Science learning involves accessing prior knowledge from long-term memory, interpretations from text, sensory information from the environment, and then interactively constructing meaning by using these data in working memory. Accessing prior knowledge involves information retrieval strategies, while inputting sensory information involves perception, decoding text involves bottom-up reading strategies, and interpreting verbal discourse involves interpersonal communication skills. The actual construction of meaning appears to be a generative process that occurs in short-term memory, which serves as a working interface between sensory input and long-term memory and where unprocessed information is rapidly lost. Short-term memory, like a workbench, has limited capacity; and efficient information processing, data management, strategy application, and executive control are required for effective utilization of this limited memory.

Learners make meaning by using top-down processes in which tentative mental models are constructed from the new information and tested against prior knowledge and socially shared standards. This process involves the dynamic reciprocals of internal hypothesizing and testing. Ruddell and Unrau (1994) said that "knowledge use and control are at the heart of the knowledge-construction process through purpose setting, planning and organizing, and constructing meaning in the form of text representation" (p. 1022). The constructed meanings are stored in long-term memory by integrating these new ideas into existing knowledge structures or by reorganizing knowledge structures to accommodate the new ideas. The entire process is orchestrated by the learners' metacognition, habits of mind, and epistemic dispositions.

This study explored the learner dimension in learning biological science topics in five elementary school classrooms instructed by different teachers using a common course of study and outcome measures. Specifically, the study addressed the associations among conceptual, metacognitive, cognitive, stylistic, and affective characteristics and science achievement. The following research questions focused the study:

1. What are the learning style profiles, from both a cognitive-based perspective and a personality-based perspective, for Grade 6/7 science students?
2. What is the relationship between the cognitive-based view of learning style and the personality-based view of learning style?
3. What are the relationships among prior conceptual knowledge, metacognitive awareness, self-management, cognitive style, preferred learning style, attitudes, self-regulation and science achievement?

Background

Ruddell and Unrau (1994) described the components of an interactive-constructive model to explain the reading process. The reader, the text, the classroom context, and the teacher form the components of their perspective. These "components are in a state of dynamic change and interchange as meaning negotiation and meaning construction take place...." Thus reading "is conceptualized as a sociocognitive interactive model that explains the reading process in the instructional context of the classroom" (Ruddell & Unrau, 1994, p. 988). While it is acknowledged that the interactive-constructive model is fundamentally a cognitive process, the importance and the role of affective factors and of the sociocultural context of learning are also recognized (Paris, 1987). The general characteristics of this learning model are not restricted to learning from text. Whether information is presented orally as in the teacher talking or in the form of pictures, videos, demonstrations or activities, the learner must still perceive and process ideas to construct meaning. The learner processes new information by moving between new information and concurrent experiences and by comparing new information and experience with personal world view recollections (Kintsch & VanDijk, 1978; Osborne & Wittrock, 1983; Yore & Shymansky, 1991).

The single most important factor in the interactive-constructive model of reading with understanding is the concept of prior knowledge. Prior knowledge in a very broad sense encompasses domain and topic prior knowledge and metacognitive prior knowledge. Alexander and Kulikowich (1994) defined domain knowledge "as knowledge of a specific field of study (e.g., physics) and topic knowledge as the knowledge of scientific concepts directly referenced in the text" (p. 897). Garner (1992) suggested that metacognitive knowledge refers to knowledge about the self as learner, the task, and the strategies used to complete the task. As Holliday (1988) suggested, "in addition to learners' knowledge and experiences about studying, learners are similarly affected by an array of cognitive and affective goals ... and strategies" (p. 3). Ruddell and Unrau (1994) considered cognitive abilities, prior knowledge, metacognition, learning preferences, and several affective factors under the umbrella of learner characteristics. The critical tasks and the classroom environment including materials, methods, and teachers represented the other important factors. It is this conception that forms the basis of the present study (Figure 1). Thus it is the intention here, within the framework of the interactive-constructive model of reading comprehension, to explore the relationships among learner characteristics and between these characteristics and science achievement.

Learner Characteristics

The learner characteristics central to learning with understanding include prior knowledge, metacognition, learning preferences usually conceived of as learning styles, and affective factors. Each of these factors potentially impacts the learning process.

Prior Knowledge

Prior topic knowledge is widely accepted as a key element among an array of learner characteristics found to significantly impact learning with understanding (Langer, 1984). Ausubel (1968) put this rather forcefully when he said, "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing

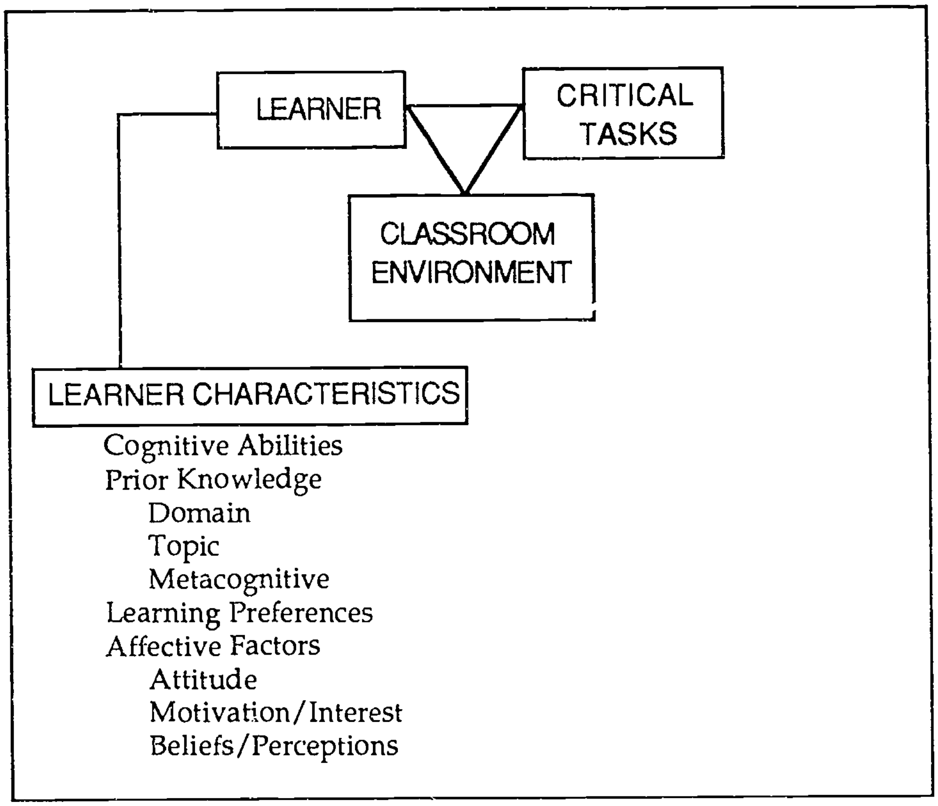

Figure 1: **Interactive-constructive model of reading--unified model**

learning is what the learner already knows. Ascertain this and teach accordingly" (p. vi). Zeitoun (1989) found that prior knowledge accounted for more variance in science learning than did cognitive development. Others suggested that prior knowledge may be more important than both text features and strategies training in impacting new learning from textual materials (Lipson, 1982).

The role of prior topic knowledge has been the focus of many research endeavors (e.g., Holmes, 1983; Lipson, 1982; Pearson, Hansen & Gordon, 1979; Schmidt, De Volder, DeGrave, Mousi & Patel, 1989). Whether referred to as invented ideas, correct conceptions, misconceptions, naive theories, intuitive ideas, common-sense knowledge, alternative frameworks, preconceptions, or children's science, prior knowledge has been found to impact reading comprehension. The more correct knowledge one has about a discipline and a topic prior to being exposed to further information about the topic, the easier it will be to understand what is read and the more successful will be new learning (Alexander & Kulikowich, 1994).

Metacognition

Metacognition, a term borrowed from developmental psychology, includes theory and research that focus upon one's thinking about thinking (Flavell, 1979; Garner, 1992; Paris, Wasik & Van der Westhuizen, 1988). While some researchers argue that metacognition remains a fuzzy concept, others focus on one or another component of metacognition and still others bemoan the lack of unanimous agreement on a definition. There is increasing agreement that metacognition consists of two interdependent components: metacognitive awareness (self-appraisal) and executive control (self-management) of cognition (Brown, 1978; Flavell, 1979).

Self-appraisal (awareness) includes declarative knowledge, that is, what is known; procedural knowledge, that is, how to do the processes involved; and conditional knowledge, that is, why and when a process is used (Jacobs & Paris, 1987). Self-management (executive control), on the other hand, is dynamic and includes three of the processes involved in self-regulated thinking. These self-regulated activities include selection of a purpose, related knowledge, goal-oriented strategies, and a heuristic assignment of time and effort to realize the goal (planning), checking or evaluating comprehension as a ongoing process (monitoring), and intentional redirection of activities or use of fix-up strategies when problems with comprehension arise (regulating) (Cross & Paris, 1988; Paris, Cross & Lipson, 1984). This perception of metacognition permits identification of the factors that affect thinking and makes it possible to conceptualize learners' knowledge about and their use of personal cognitive resources. "What children know about the goals, tasks, and strategies of reading can influence how well they plan and monitor their own reading" (Jacobs & Paris, 1987, p. 255).

Learning Preferences

"People differ in the habitual ways they react to tasks" (Pressley, Goodchild, Fleet, Zajchowski & Evans, 1989, p. 305). The collective wisdom among many elementary school teachers posits a link between learning preferences and effective learning processes. The interactive-constructive model of learning suggests that students are indeed unique in the way they construct meaning from their environment.

Learning styles loosely defined as habitual ways of responding can also be considered to be consistent and persistent modes of "organizing and processing information and experiences" (Messick, 1984, p. 61). When described as 'usual modes of acting or habits', the suggestion is that cognitive styles (a) develop slowly over the long term, (b) described as 'preferences' imply some degree of modifiability, (c) and described as 'persistent' suggest pervasiveness across broad domains. Cognitive style (field-dependence, field-independence) has probably received the greatest research attention, and it is this dimension that has had the greatest application to education (Witkin, Moore, Goodenough & Cox, 1977). Studies of field dependence-independence have been carried out "in areas as diverse as interpersonal behavior, learning and memory, perceptual constancies, defense mechanisms, automatic nervous system processes, cultural differences, dreaming, schizophrenia, child-rearing, laterality, and moral judgment" (Witkin, 1978, p. 5). Cognitive style has been demonstrated as a significant influence on science achievement in an inquiry context (Shymansky & Yore, 1980; Yore, 1986).

The Group Embedded Figures Test (GEFT) is a perceptual assessment procedure used to measure field-dependence and field-independence. The student is required to locate a previously seen figure within a larger figure. Results from this test provide information about how a learner "processes and stores information, and how it retrieves that information " (Martin, 1985, p. 25). The ability to overcome an embedding context allows the individual an analytical way of experiencing (Witkin, Oltman, Raskin & Karp, 1971). The dimension of field-dependence-independence represents, at the extremes, differing ways of approaching an experience and as such may be termed a global versus an analytical dimension of functioning. There is the further suggestion that this aspect of cognitive style is part of a broader dimension labelled psychological differentiation (Witkin et al., 1971).

It has been suggested that cognitive styles, rather than simply being a cognitive perception-processing attribute, are a facet of personality and, indeed personality in a very general sense may underlie styles of learning (Entwistle & Ramsden, 1983). Messick (1984) noted that styles are more deeply rooted in personality than is usually implied when he suggested that styles are "characteristic self-consistencies in information processing that develop in congenial ways around the underlying personality traits" (p. 61). Reiterating and extending this point, Messick (1994) pointed to the need to determine how styles are organized within personality. If a close parallel between cognitive style and personality type could be demonstrated, it would allow a move toward a more comprehensive theory of learning style.

Hanson (1987) attempted to demonstrate the connection between learning style and personality by infusing his view of learning style in existing personality theory. Using Jung's type theory and the behavioral definitions of the Myers-Briggs Type Indicator (MBTI), Hanson developed a personality-based conception of learning style. Accordingly, he suggested learning types or preferences based on two perceptual functions (sensing and intuition) and two functions for making judgments (thinking and feeling). Silver and Hanson (1982) proposed four learning types: sensing-thinking (ST), sensing-feeling (SF), intuition-thinking (NT), and intuition-feeling (NF). Each of these styles is characterized "by whatever interests, values, needs, habits of mind, surface traits and learning behavior naturally result from" the four style types (Silver & Hanson, 1980, p. 2). An attitudinal dimension of introversion and extroversion was considered to modify the functions of perception and judgment. Thus attitudinal dispositions are demonstrated in the preferred ways for dealing with ideas and tasks (Silver & Hanson, 1986).

Learners described as sensing-thinking (ST) are characterized as practical, efficient, and results oriented. These learners prefer to perceive through their senses and make decisions based on thinking and logical consequences. Sensing-feeling (SF) learners tend to be sociable and interpersonally oriented, and their learning interests focus on people and not facts or theories. As with the ST learners, SF learners prefer to perceive through their senses but they make their judgments based on personal feelings of likes or dislikes. Intuition-thinking (NT) learners are characterized as knowledge oriented and theoretical and motivated by complex problems. These learners prefer to perceive through intuition rather than their senses and make decisions based on thinking rather than feelings. Learners described as intuition-feeling (NF) tend to be imaginative, creative, and insightful. They perceive through intuition and make decisions by using their feelings. For these people their intuition is focused on people and values.

Silver and Hanson (1978) developed the Learning Preference Inventory (LPI) to assess student learning preferences. Using the LPI the respondent is asked to rank four choices to complete a given stem from most to least preferred. The results identify learner preferences across the four personality-based learning styles and provide descriptions of how learners in each style group prefer to learn. Hanson, Silver, and Strong (1984) suggested that in regular school populations 35% of the students are SF learners, 26% are ST learners, 12% are NT learners, and 27% are NF learners. They further suggested that among gifted students 52% of learners are NF with the remaining three learning styles being relatively equal in distribution. They also found that most teaching favors NT learners and suggested that classrooms needed to accommodate the variety of learning styles. Detailed instructional suggestions for each learning type and materials aimed at providing guidelines for planning, implementing, and evaluating instruction, as well as sample lessons for elementary and secondary school levels have been provided (Silver & Hanson, 1982; Silver & Hanson 1986; Strong, Hanson & Silver, 1986).

Schmeck (1983) suggested that attempts to relate cognitive and personality factors had fallen short of expectations. He said, "no doubt the differences we observe will ultimately be explained by more basic theories of personality and cognitive styles ...." (Schmeck, 1983, p. 235). Adequate assessment of learning styles should result in "instruction tailored to the needs and capabilities of the individual child" (Harris & Pressley, 1991, p. 394). Attribute-treatment-interaction (ATI) research has generally not been compelling; however, learning style information in combination with prior knowledge, metacognition, and attitude may be used to help both learners in their meaning construction process and teachers in their instructional process as they move students along the way to becoming independent self-regulated learners. A recent meta-analysis of 36 studies using a multi-dimensional learning styles model revealed an effect size of .384 for matched teaching and learning styles (Dunn, Griggs, Olson, Beasley & Gorman, 1995). Unfortunately, the studies used in this meta-analysis come from a rather small research community.

Affective Factors

There has been a tendency among some researchers (Cross & Paris, 1988; Flavell, 1979; Paris, Wasik & Turner, 1991) to include affective factors under the rubric of metacognition. "Some argue that metacognition involves emotions and motivation, whereas others suggest that it is better conceptualized as knowledge without affect" (Jacobs & Paris, 1987, p. 258). Recent science reform utilizes a similar collective construct called habits of mind composed of attitudes, values, science processes, and critical response skills (AAAS, 1993). These broader concepts might serve to contribute to the perceived fuzziness of the concept of metacognition. It could be more useful to separate out affective features from metacognition yet maintain it under the umbrella of learner characteristics. Such a separation would allow a more focused view of metacognition on the one hand and appropriate emphasis on affective features on the other. Thus it could be possible to more clearly determine the relative impact of metacognition and affective factors on reading comprehension.

The impact of affective factors on learning cannot be underestimated. Student motivation, attitude, and interest function to significantly impact learning outcomes. During the course of their school careers, students develop self-perceptions or beliefs about their abilities to do academic tasks; this affects their motivation to be successful, their interest, their tendency to persist or to give up, and their propensity to learn and use strategies (Pressley, et al., 1989).

Method

This study utilized a pretest-posttest case study design involving five intact classes of an upper elementary school in Victoria, B.C., Canada. The five teachers instructed their own class about two biology topics utilizing guided inquiry with embedded comprehension instruction. This paper is limited to exploration of learner characteristics and science achievement.

Subjects

The host school served a culturally mixed, English-speaking population with a majority representation from lower and middle socio-economic groups. The subjects for this study were 109 upper elementary school students, 56 males and 53 females. The students were members of naturally constituted classes of Grades six and seven. There were 52 Grade six students and 57 Grade seven students distributed across two Grade six classes, two Grade seven classes, and one Grade six/seven split class.

Instruction Unit

The instruction involved a four-part, guided inquiry approach with explicit science reading instruction embedded. The content focus of the 12-week science unit was control systems of the body, life cycles, and new generations (Yore, Beugger, McDonald & Harrison, 1990). Each week the classes explored science activities and science text three to four times for 40 minutes. A typical lesson consisted of an introductory activity to access prior knowledge, set purpose, and motivate students; an experience with a concrete science activity; a post-experience discussion with explicit reading instruction and reading assignment; and an informal assessment activity. It frequently took two or three time blocks to complete a lesson.

Instruments

The outcome variable (science knowledge) and learner characteristics (prior conceptual knowledge, metacognitive awareness, metacognitive self-management, cognitive style, perception-judgment style, attitude, and self-assessment) were measured using established approaches. Science knowledge was measured by a published test associated with the instructional materials. Metacognitive awareness was measured by the Index of Science Reading Awareness (ISRA). Metacognitive self-management was measured by an objective test based on the ISRA design. Cognitive style was measured by the Group Embedded Figures Test (GEFT). Perception-judgment style was measured by the Learning Preference Inventory (LPI). Attitude and self-regulation were measured with Likert-type items.

Science Knowledge

Prior conceptual knowledge (PCK) and science achievement (SK) were measured by a 19-item objective test. The multiple-choice, fill-in-the-blank, and short answer items were selected from a pool of validated items associated with the target topics of the instruction. The internal consistency was 0.53.

Index of Science Reading Awareness (ISRA)

The ISRA is a 63-item multiple-choice survey with open response option designed to measure metacognitive awareness (MA). The internal consistencies of the ISRA reported for the total test is 0.88 (Yore, Craig & Maguire, 1994). Construct, concurrent, predictive, and structural validities were supportive of the desired image of an effective, efficient science reader and the ISRA.

Science Reading Self-Management

The design features of the ISRA were extended into the metacognitive self-management (MSM) domain for four science reading strategies: accessing prior knowledge, identifying and using text structure, finding main ideas, and writing summaries. Each strategy was assessed with a planning item, a monitoring item, and a regulating item (Jacobs & Paris, 1987). Holden (1996) found marginal internal consistency for the 12-item self-management test (0.59, 0.69).

Group Embedded Figures Test (GEFT)

The GEFT (Oltman, Raskin & Witkin, 1971) was used to determine cognitive style along the continuum of field-dependence to field-independence. The GEFT is a 25-item, timed perceptual-analysis task (seven items constitute a non-scored practice section). For each item subjects are presented with one of eight possible target designs that they are required to find and trace in a complex design. The target designs are presented on the back cover of the text booklet and are available to the subjects for repeat reference. Items are scored as either completely correct, which receives a score of 1, or incorrect, which is scored 0. Total test score possibilities range from 0 to 18. The Spearman-Brown reliability for the GEFT was reported as 0.82.

Hanson-Silver Learning Preference Inventory (LPI)

The LPI (Silver & Hanson, 1978) was used to determine personality-based perception-judgment styles for the subjects. The LPI is a non-timed, 144-item task that measures preferences for perception and judgment. The subjects are given 36 sentence stems with four completion choices. The task is to rate each completion choice from one to four with one meaning most preferred choice through to four meaning least preferred choice. A weighted scoring scheme is used so that the higher preferences are assigned the higher score (4) and the lower preferences are assigned a lower score (1). Four separate score totals are obtained, one for each style of learning (SF—sensing/feeling, ST—sensing/thinking, NT—intuiting/thinking, NF—intuiting/feeling. Finally, subjects may be described according to their perception function, that is, sensing or intuition, and according to their judgment function, that is, thinking or feeling. Test-retest reliability for the LPI was reported as 0.89 (Silver & Hanson, 1980).

Attitude toward School Science (IAS)

A 20-item attitude survey (IAS) attempted to assess students' attitude toward school science, science books, and school. The IAS was developed from a variety of attitude surveys including parts of the British Columbia Assessment of Science (Bateson, Anderson, Dale, McConnell & Rutherford, 1986) and the British Columbia Assessment of Written Expression (Jeroski, 1988). The Likert-type items were randomly placed in the survey form with the task direction being simply to check the box that best reflected the subjects' feelings toward a presented statement. Response to each item varied along a five-choice continuum from strongly agree to strongly disagree. Internal consistency was 0.91.

Self-Regulation (SR)

The students' self-regulation (SR) of success in school and science was measured by four Likert-type items. This cluster of items was identified by a factor analysis that is an indication of the students' self-evaluation of their academic achievement and their independent learning and general study habits.

Data Collection and Analysis

The tests were administered during three blocks of time—pre-instruction, during instruction and post-instruction (Table 1). The pre-instruction cluster of tests included the GEFT, the extended ISRA, and the conceptual test. The tests were administered by the researcher in the regular class groupings. The GEFT took approximately one-half hour per class. The extended ISRA required approximately 45 minutes for each class to complete, and the conceptual test was completed usually in less than thirty minutes for each class. The LPI was administered mid-way through the unit of study on control system of the body, life cycles and new generations. The LPI took each approximately 40 minutes to complete. The science achievement test was administered directly after the completion of the unit of study. The science achievement test took approximately 30 minutes per class. The IAS was administered approximately one month later as a post hoc decision to clarifying informal research observations made in the classrooms. The IAS took each class approximately 20 minutes.

Table 1

Chronology of the Events of the Study

Date	
15 - 18 February	Group Embedded Figures Test (GEFT),
" "	Metacognition Test (Extended ISRA)
19 February	Conceptual Test
22 February - 14 May	Science Study Units
22 March	Learning Preference Inventory (LPI)
18 May	Science Achievement Test
22 June	Informal Attitude Survey (IAS)

Results

The results for the three research questions are presented in two clusters. Questions 1 and 2 were concerned with cognitive style and personality-based learning style and with the relationships between these two styles are considered together. Question 3 was concerned with the relationships among the learner characteristics and science achievement. This question is the focus of the second set of results.

Cognitive Learning Style

Scores on the cognitive style Group Embedded Figures Test (GEFT) do not represent two distinct style types but rather represent a continuous distribution. Thus definitions of field-dependence and field-independence tend to be arbitrary decisions. For purposes of some of the more detailed analyses of this study, conservative estimates were used with scores from 0 to 4 being defined as field-dependent and scores from 14 to 18 being defined as field-independent.

The distribution of scores obtained on the GEFT are presented in Figure 2. Overall the distribution presents a positive skew with 28% of the subjects testing out as field-dependent (0-4) and 16% of the subjects testing out as field-independent (14-18). This is consistent with expectations where generally it has been found that between the ages of 8 and 15 there is a continuous increase in field-independence (Witkin, et al., 1971).

Gender differences have been found repeatedly such that males tend to be more field-independent than females (Witkin, et al., 1971). The present study did not support this expectation. The means, standard deviations, and range values across subjects and for males and females are presented in Table 2. The difference in the average GEFT scores between males and females were tested using a t-test (Table 3). The difference was not statistically significant. An inspection of the category data reveals that 30% of the males and 26% of the females tested out as field-dependent (0-4) and 16% of the males and 15% of the females tested out as field-independent(14-18).

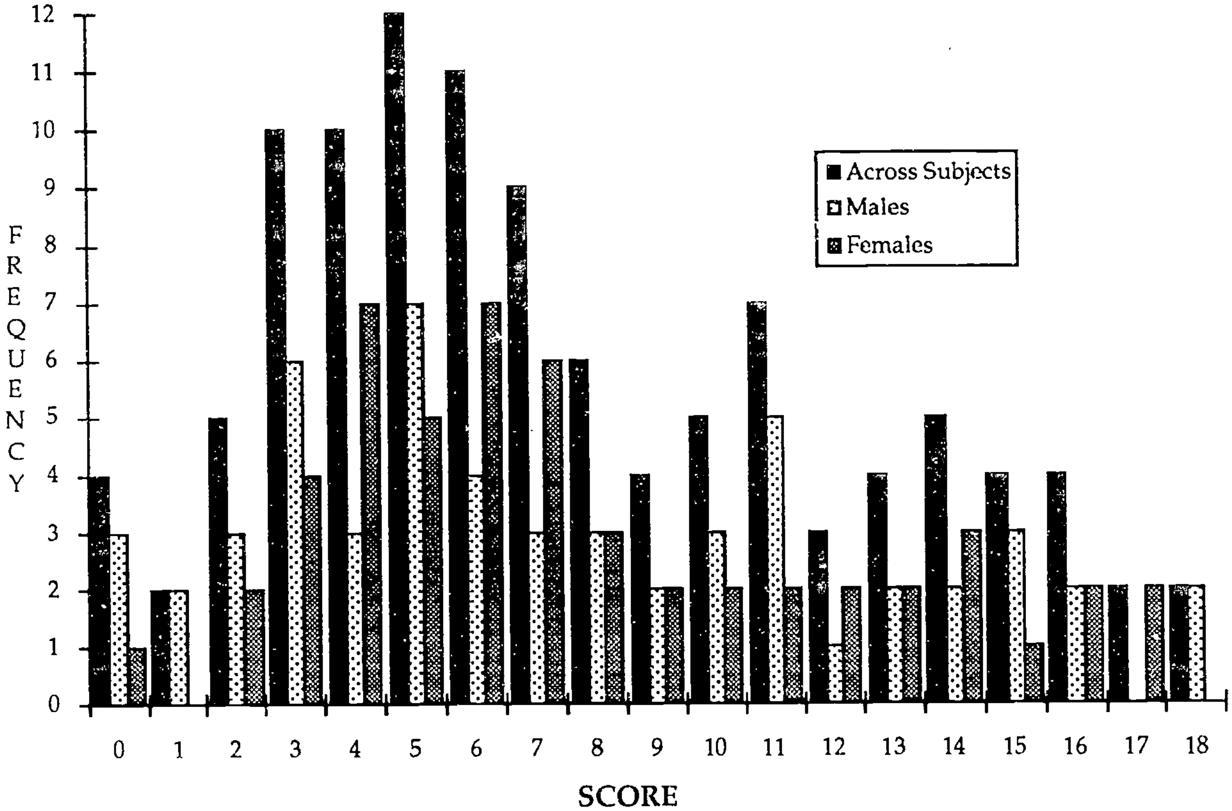

Figure 2: Distribution of scores on the GEFT across subjects and by gender.

Table 2

Mean, Standard Deviation, and Range Values for the GEFT across Subjects and by Gender.

Variable	Gender	N	M	S.D.	Range	Minimum-Maximum
GEFT	across subjects	109	7.65	4.64	18	0-18
	M	56	7.57	4.94	18	0-18
	F	53	7.74	4.34	17	0-17

Table 3

T-tests for Independent Samples of Gender on the GEFT.

Variable	Gender	N	Mean	S.D.	t	df	2-tail probability
GEFT	M	56	7.57	4.94	-.18	107	.854
	F	53	7.74	4.34			

Personality-Based Learning Style

The personality-based view of learning style assessed by the Learning Preference Inventory (LPI) provides information about learner preferences regarding four style types (sensing-feeling SF, sensing-thinking ST, intuition-thinking NT, and intuition-feeling NF) and two attitude preferences (introversion I, and extroversion E). The focus of the present study was limited to the four learning style types. The LPI literature does not address gender variations, nor were any references regarding gender differences found for this personality-based view of learning style. However, gender differences were reported for cognitive style measures; and these findings prompted ad hoc investigations of the LPI data regarding gender.

The LPI allows three major avenues for examining score results. The results may be analyzed according to the strength of preference for each of the four learning types (SF, ST, NT, and NF) so that the focus is on category levels. The results may also be analyzed using dominant, auxiliary and supportive designations, which are determined by the intrasubject scores obtained for each of the four learning styles. These designations, however, do not in any way represent strength of preference. Finally, the results may be examined by determining the separate perception and judgment functions, which reflect the preferred ways of receiving and processing information. These three perspectives organized the analyses and discussion of the LPI data.

Examination of test scores from a category perspective allows description of the four learning styles. The scores obtained on each of the four learning styles are categorized based on the values provided by Silver and Hanson (1980). Subjects are described as having little or no preference (0-24), some preference (25-49), moderate preference (50-74), high preference (75-99), or very high preference (100-125) for each of sensing-feeling (SF), sensing-thinking (ST), intuition-thinking (NT), and intuition-feeling (NF) learning styles.

The category of perception function describes ways in which information may be received. Information may be received by sensing (S) or by intuition (N). The category of judgment function describes ways in which information may be acted upon. Information may be acted upon by thinking (T) or by feeling (F).

Category Analyses

The graphic representation of the data according to category preferences are presented in Figures 3 through 6. Distribution of preferences for the sensing-feeling (SF) category learning type showed the greatest variation as can be seen in Table 4. Almost 80% of the subjects showed moderate or stronger preference for the sensory-feeling (SF) type of learning (Figure 3). The SF learning style has been found to be associated with academic difficulties. Using research support from the Myers Briggs Type Indicator (MBTI), Hanson (1987) suggested that the SF learning style is most often associated with the school drop-out. The 20% of the sample who showed little or some preference for this type of learning were mostly males (Figure 3). Table 5 shows significant differences (p= .001) between males and females such that females showed significantly higher preferences than males for the SF learning style. The mean for the SF style for females was 71.51; for males, the mean was 55.16.

As a group none of the subjects showed a very high preference for the sensing-thinking (ST) learning style, and only 15% of the subjects showed a high preference for the ST style (Figure 4). The ST learning style is associated with academic success (Barker, Gulkus, Huber, Rose & Rowe, 1982). Most of the subjects, 85% showed moderate or less preference for this type of learning (Figure 4). Male and female preferences were fairly equal within this category preference so that there were no significant differences (p= .442) between male and female preferences as can be seen in Table 5. The mean for the ST learning style for males was 58.79; for females, the mean was 56.68.

Only 4% of the subjects showed a high preference for the intuition-thinking (NT) learning style (Figure 5), which is the learning type most often associated with the highest academic success (Barker, et al., 1982). Indeed the majority of the subjects, (62%) showed only some preference for this type of learning, and a further 13% showed little or no preference for this type of learning (Figure 5). The 13% were all females. Table 5 illustrates that males have a significantly (p= .003) stronger preference for the NT learning style than females. The average for males on the NT learning style was 44.75 and the average for the females was 35.72.

There was a tight clustering around the moderate preference for the intuition-feeling (NF) learning style with 50% of the sample showing a moderate preference for the NF style. A further 25% of the sample showed high preference for the NF learning style (Figure 6). One-quarter of the subjects showed less than moderate preference for the NF style. The NF learning preference has been found to be associated with those students identified as gifted (Hanson, Silver & Strong, 1984). There was no significant difference (p= .118) between male and female NF scores.

Little = 0-24
Some = 25-49
Moderate = 50-74
High = 75-99
Very High = 100-125

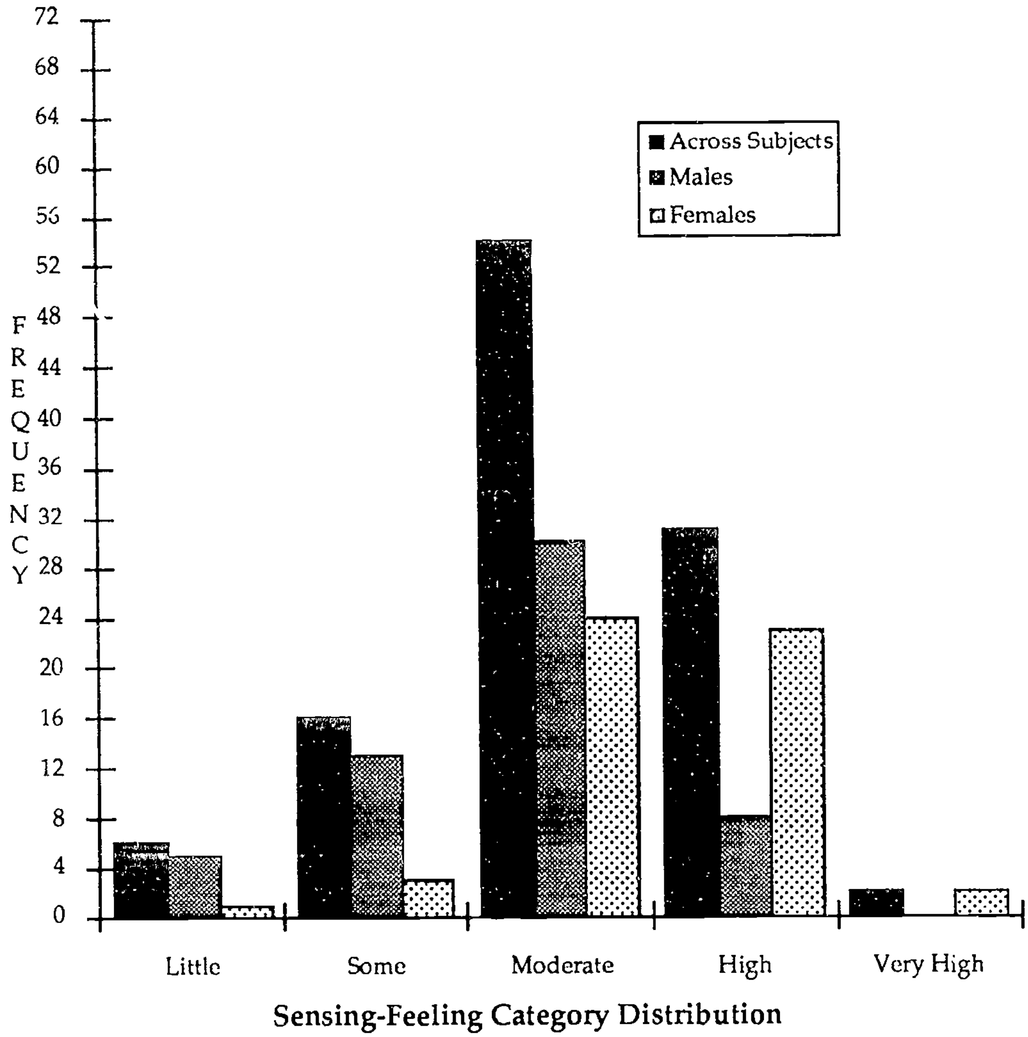

Figure 3: Category distribution for the sensing-feeling learning preference across subjects and by gender.

Little = 0-24
Some = 25-49
Moderate = 50-74
High = 75-99
Very High = 100-125

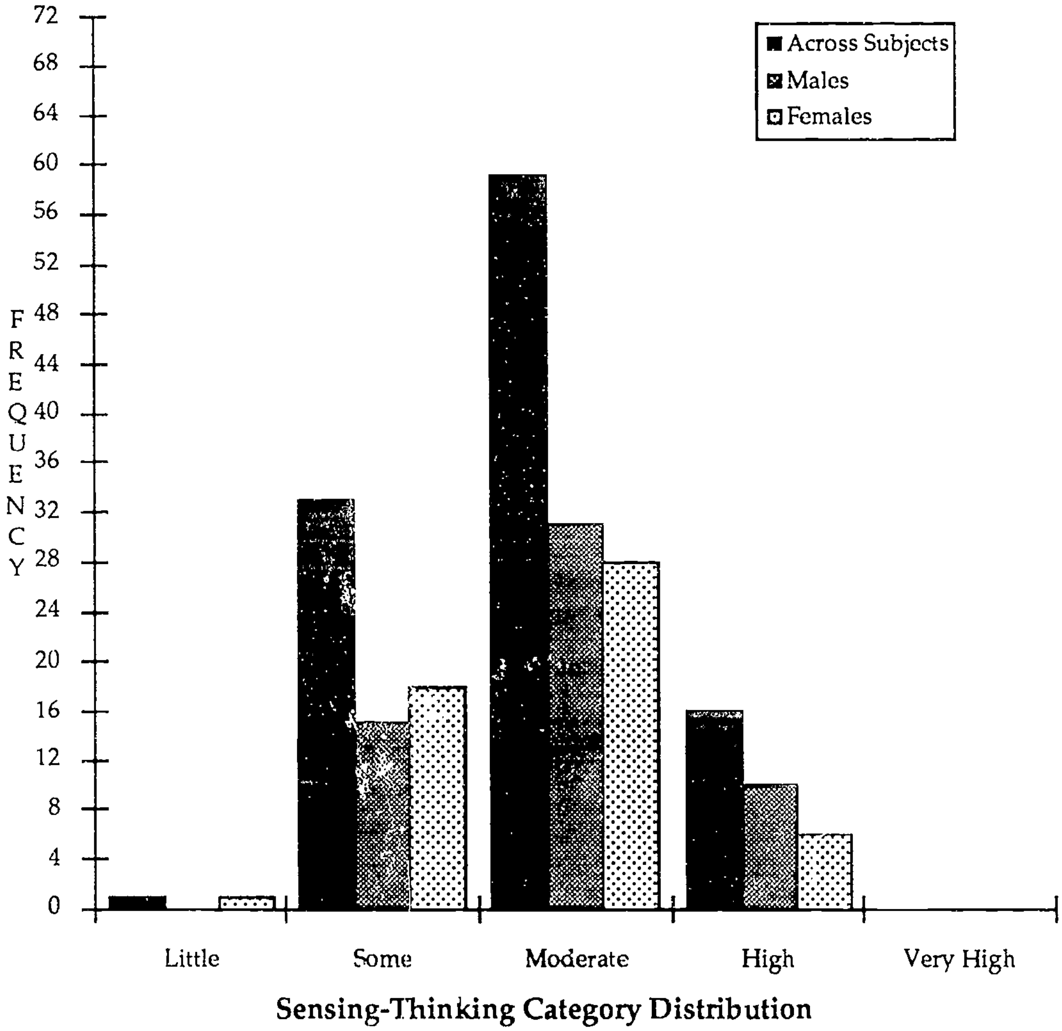

Figure 4: Category distribution for the sensing-thinking learning preference across subjects and by gender.

Little = 0-24
Some = 25-49
Moderate = 50-74
High = 75-99
Very High = 100-125

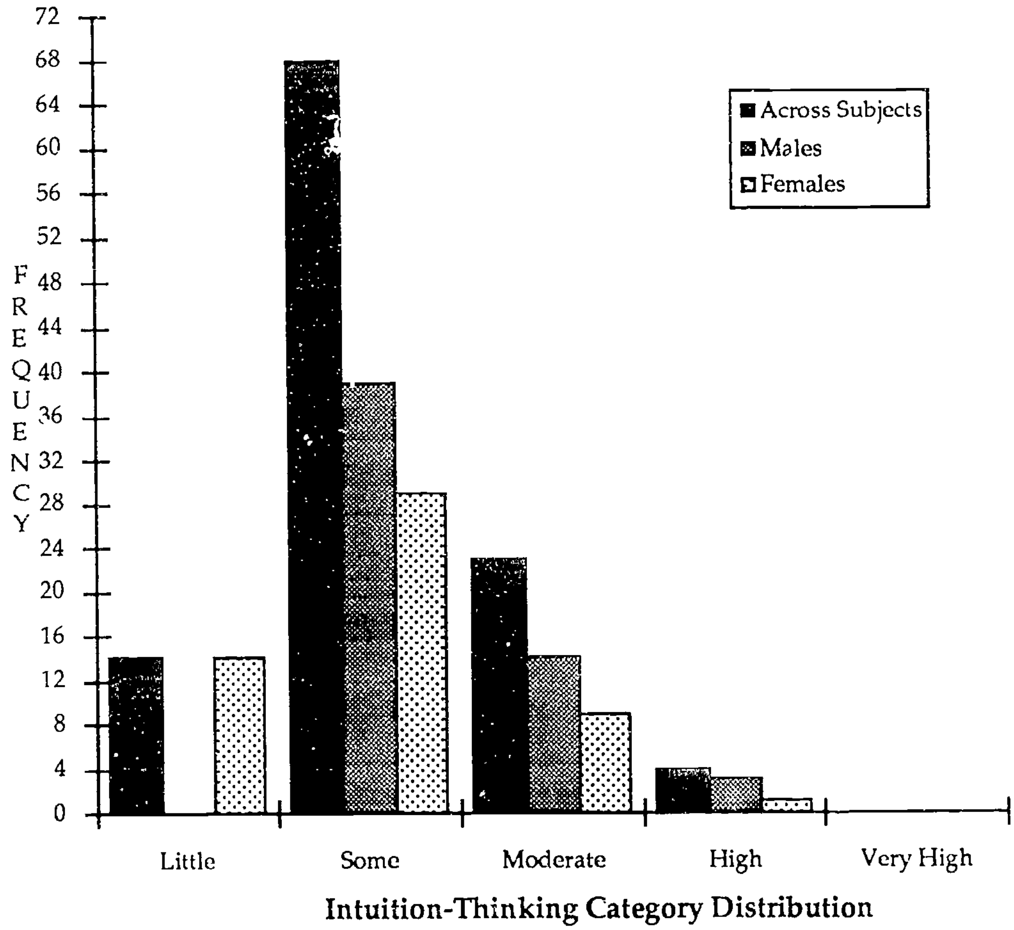

Figure 5: Category distribution for the intuition-thinking learning preference across subjects and by gender.

23

Little = 0-24
Some = 25-49
Moderate = 50-74
High = 75-99
Very High = 100-125

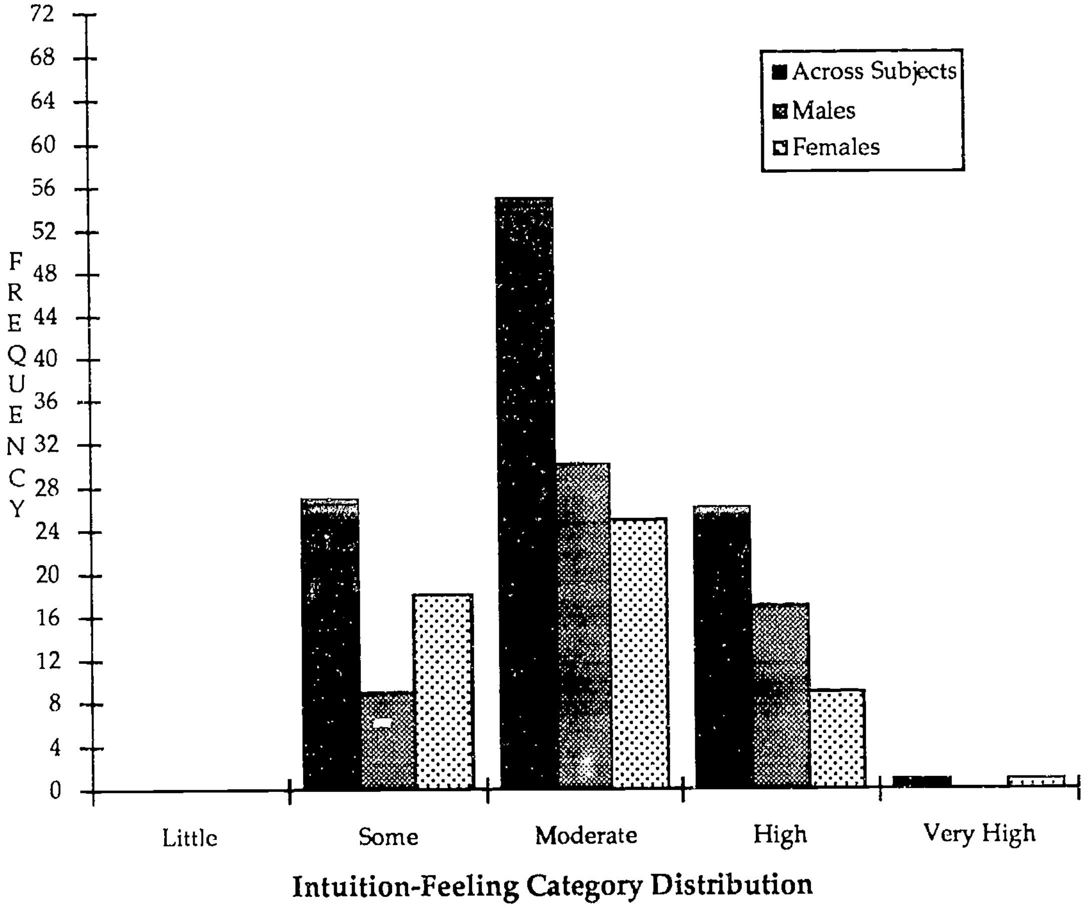

Figure 6: Category distribution for the intuition-feeling learning preference across subjects and by gender.

Table 4

Mean, Standard Deviation, and Range Values for the LPI Category Styles across Subjects and by Gender.

Variable LPI Category Styles	Gender	N	M	S.D.	Range	Minimum-Maximum
SF-Category	across subjects	109	63.11	19.04	102	5-107
	M	56	55.16	18.11	86	5-91
	F	53	71.51	16.30	84	23-107
ST-Category	across subjects	109	57.76	14.21	75	22-97
	M	56	58.79	13.75	62	28-90
	F	53	56.68	14.73	75	22-97
NT-Category	across subjects	109	40.36	15.83	85	8-93
	M	56	44.75	15.24	67	26-93
	F	53	35.72	15.23	79	8-87
NF-Category	across subjects	109	62.42	16.72	82	25-107
	M	56	64.86	16.51	68	25-93
	F	53	59.85	16.71	81	26-107

Table 5

T-tests for Independent Samples of Gender on LPI Category Styles.

Variable LPI Category Styles	Gender	N	M	S.D.	t	df	2-tail probability
SF-Category	M	56	55.16	18.11			
	F	53	71.51	16.30	-4.94	107	.001
ST-Category	M	56	58.79	13.75			
	F	53	56.68	14.73	.77	107	.442
NT-Category	M	56	44.75	15.24			
	F	53	35.72	15.23	3.09	107	.003
NF-Category	M	56	64.86	16.51			
	F	53	59.85	16.71	1.57	107	.118

Dominant Category Analyses

The Learning Preference Inventory (LPI) data may be examined according to the pattern of scores for an individual. The highest of the four learning style scores represents the dominant type, the next highest score represents the auxiliary type, the third highest score represents the supportive type, and the lowest score is thought to be the least preferred style (Silver & Hanson, 1980). Thus, the dominant learning style designation does not indicate the actual strength of the preference. When three of the four type scores are close together in value, the pattern is considered to be balanced. Given that much of the interpretation of the four type scores involves subjective determination of the proximity to or distance from other scores, it was decided to focus on the dominant type score for these analyses. Two subjects were deleted from the dominant style analyses because tied scores prevented determination of a dominant learning style.

The results of this analysis are presented in Figure 7. It can be seen that the subjects were primarily sensing-feeling (SF) dominant type learners with 41% of the subjects, 14 males and 31 females, demonstrating this type as dominant. In a study comparing gifted school populations and regular school populations Hanson et al. (1984) found that in regular school populations 35% of the students demonstrate SF as their dominant learning type.

The sensing-thinking (ST) and intuition-thinking (NT) learning types were least preferred with 18% (13 males, 7 females) and 7% (5 males, 3 females) respectively choosing these types as dominant (Figure 7). Hanson et al. (1984) found that 26% of the students demonstrated the ST type as their dominant type and 12% demonstrated NT as their dominant type.

The intuition-feeling NF type was dominant for 32% of the subjects compared with 27% in the Hanson et al. (1984) study. In the present study NF learning style was dominant for 41% of the males and 21% of the females.

Dominant Perception and Judgment Functions Analyses

The dominant perception function describes the way in which a person prefers to receive information. Two dominant perception functions are described such that a person will usually prefer either the sensing (S) or the intuition (N) function. The dominant judgment function describes the way in which a person prefers to make judgments about information. Two dominant judgment functions are also described such that a person will usually prefer either the thinking (T) or the feeling (F) function. Using this interpretation approach a person may evidence a dominant perception or a dominant judgment function but not both.

The two highest scores are used to determine the dominant perception and dominant judgment functions. If the first letter describing the two highest learning style scores are the same (either S or N), the dominant perception function is described as sensing (S) or intuition (N) respectively. If the second letters describing the two highest learning style scores are the same (either T or F), the dominant judgment function is described as thinking (T) or feeling (F) respectively. There may be situations where there is no clear dominance for either the perception or judgment functions.

Silver and Hanson (1980) suggested that "the chances are that either the perception or the judgment function will be the same for both the first and second choices" (p. 29). As can be seen in Figure 8, the present results were not consistent with this expectation. Indeed, the majority of these subjects did not show either a dominant perception or a dominant judgment function, as defined by Silver and Hanson (1980). Using the LPI procedure it was found that 60% of the students, 33 males and 33 females, did not evidence a dominant perception function; and 64% of the subjects, 42 males and 28 females, did not evidence a dominant judgment function.

With the large percentage of students not demonstrating a dominant perception or judgment function, the percentages of dominant perception and judgment functions were very different from that reported by Hanson et al. (1984). In the present study it was found that 31% of the subjects showed a dominant sensing perception, compared with the Hanson et al. (1984) study where 61% showed the sensing perception. Only 8% of the subjects showed a

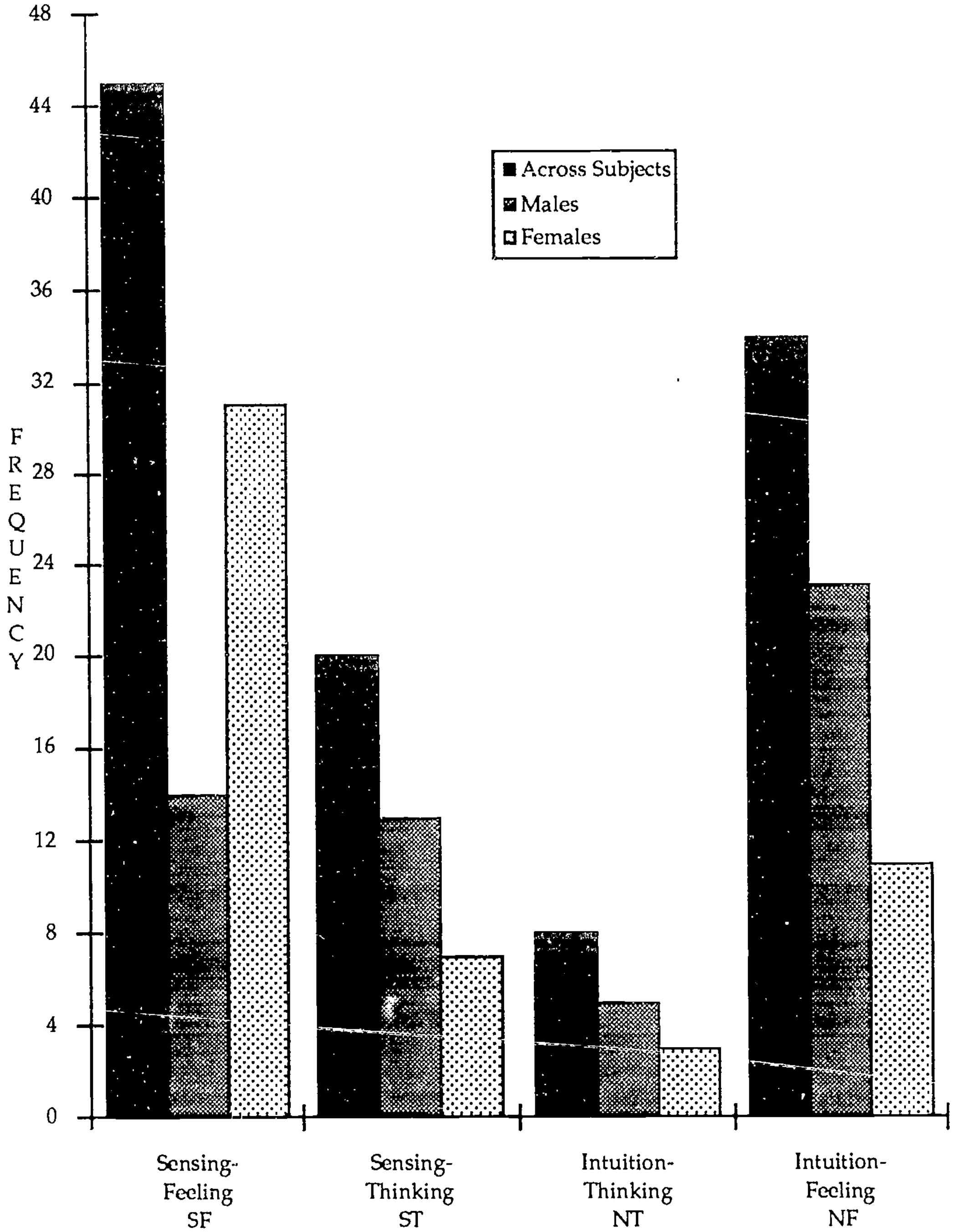

Figure 7: Dominant learning preference on the LPI across subjects and by gender.

dominant intuition perception, compared with 39% in the Hanson et al. (1984) study. In terms of the dominant judgment function 4% showed a preference for the thinking dominant judgment, compared with 38% in the Hanson et al. (1984) study. Figure 8 shows that 32% showed a preference for the feeling dominant judgment, compared with 62% in the Hanson et al. (1984) study.

Relationship Between Cognitive and Personality-based Learning Styles

The relationship between cognitive learning style, as measured by the GEFT, and personality-based learning style, as measured by LPI, was investigated through a series of correlations and t-tests. In some cases cell sizes were too small to allow useful comparisons.

The first analysis examined the relationship between GEFT and LPI category levels, across subjects, and for males and females separately (Table 6). There were no significant relationships across subjects between the GEFT and any of the LPI measures. Both SF and ST styles were negatively correlated with GEFT, and NT and NF styles were positively correlated with GEFT. A moderate positive relationship was found between GEFT and NT dominant learning style.

The correlations between GEFT and LPI scores for the two genders taken separately were more interesting. A significant negative correlation between the GEFT and SF style for males was found. No other associations for male subjects were significant. A significant positive correlation between GEFT and SF style for females was found. No other associations involving female subjects were found to be significant. The opposite directions of the significant associations between cognitive style and sensory-feeling learning preference indicates an unexpected gender difference that requires further investigation.

Field-Dependent or Field-Independent Style and LPI

The relationship between cognitive style and personality style was also investigated by analyzing field-dependent students' (GEFT scores 0-4) and field-independent students' (GEFT scores 14-18) personality-based styles (LPI). Comparisons were made between field-dependent students' personality-based category styles (Table 7). Comparisons were also made between field-independent students' personality-based category styles (Table 8).

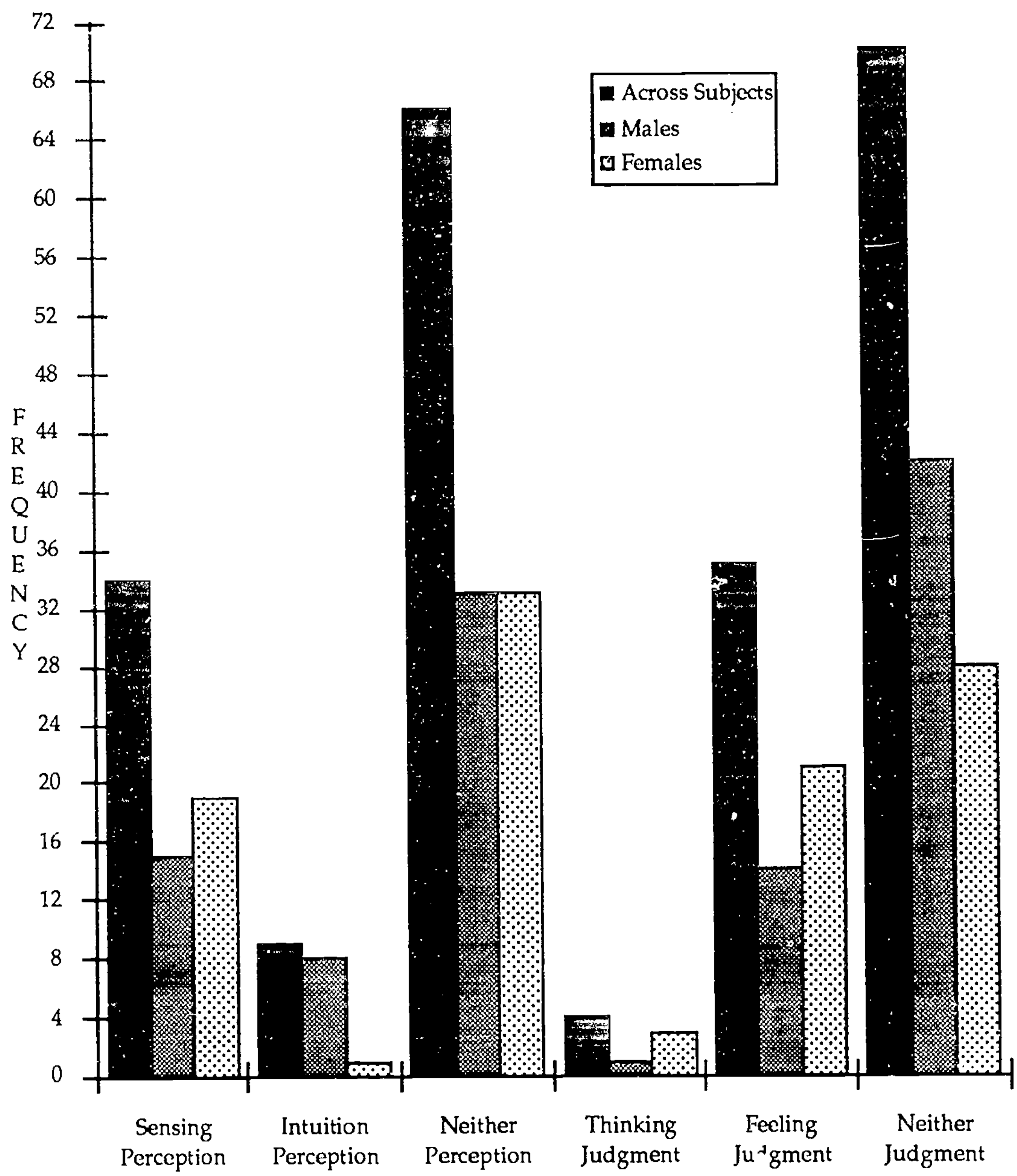

Figure 8: Distribution for the d^minant perception and judgment functions including the frequency of no perception or no judgment function.

Table 6

Correlation Coefficients of the GEFT with the LPI Category across Subjects and by Gender.

Variable	N	GEFT Across Subjects	N	GEFT Males	N	GEFT Females
SF Category	109	-0.04	56	-0.30*	53	0.27*
ST Category	109	-0.14	56	-0.08	53	-0.20
NT Category	109	0.09	56	0.22	53	-0.05
NF-Category	109	0.10	56	0.25	53	-0.08

* $p<.05$

The results of t-tests of the field-dependent style with LPI category styles revealed several significant ($p< .05$) pair-wise comparisons. There was a significant difference between sensing-feeling (SF) and sensing-thinking (ST) styles for field-dependent subjects ($p= .009$). Thus field-dependent subjects were more likely to have an SF style score than an ST style score. A significant difference was also found between SF and intuition-thinking (NT) styles for field-dependent students ($p= .001$), such that field-dependent subjects tended to have a higher SF style score than NT style score. However, there was not a significant difference between SF and intuition-feeling (NF) style scores nor was there a significant difference between the ST and NF style scores for the field-dependent students. There was a significant difference between ST and NT style scores for field-dependent subjects ($p= .001$), such that field-dependent subjects have a higher ST style score than NT style score. There was also a significant difference between NT and NF style scores for field- dependent subjects ($p= .001$), such that field-dependent subjects have a higher NF style score than NT style score.

Table 7

T-tests of Field-Dependent Subjects' Differences in LPI Category Styles and Category Perception and Judgment Functions Across Subjects

Variable LPI Category Styles and Functions	N	M	S.D.	t	df	2-tail probability
SF-Category	31	66.48	14.14	2.80	30	.009
ST-Category		58.26	13.51			
SF-Category	31	66.48	14.14	6.84	30	.001
NT-Category		37.39	11.87			
SF-Category	31	66.48	14.14	1.20	30	.240
NF-Category		60.32	18.36			
ST-Category	31	58.26	13.51	5.48	30	.001
NT-Category		37.39	11.87			
ST-Category	31	58.26	13.15	-.39	30	.696
NF-Category		60.32	18.36			
NT-Category	31	37.39	11.87	6.27	30	.001
NF-Category		60.32	18.36			

Overall field-dependent students in this study have highest SF style scores and lowest NT style scores, with NF style scores slightly higher than ST style scores positioned between the extremes (SF>NF, ST>NT). When considered along gender lines, the pattern of significant and nonsignificant results for the category style comparisons were the same except for one comparison. Field-dependent males were not significantly different for the SF and ST styles, but field-dependent females tended to be SF rather than ST style. These results generally match the expected perception and judgment characteristics of field-dependent people.

The results of t-tests of the field-independent students for differences between category styles revealed only one significant comparison. There was a significant difference (p= .007) between the intuition-thinking (NT) style scores and the intuition-feeling (NF) style scores for field-independent subjects. Field-independent subjects tended to have higher NF scores than NT style scores.

In summary, field-independent subjects tended to have highest NF style scores, closely followed by the SF and ST style scores with NT style scores being the lowest (NF>SF, ST>NT). This result appears to mask the gender difference found in the correlations of the GEFT and LPI data (Table 6). Therefore, an inspection of the field-independent males and females learning style preferences was conducted. Field-independent males also tended to be NF style, while field-independent females tended to be SF style. These results did not entirely match the expectations for field-independent students who were expected to demonstrate higher intuiting and thinking attributes.

Table 8

T-tests of Field-Independent Style with Paired Samples of LPI Category Styles and Category Perception and Judgment Functions across Subjects.

Variable LPI Category Styles and Functions	N	M	S.D.	t	df	2-tail probability
SF-Category	17	59.59	24.98	.45	16	.661
ST-Category		56.47	13.63			
SF-Category	17	59.59	24.98	1.29	16	.215
NT-Category		45.71	22.65			
SF-Category	17	59.59	24.98	-.25	16	.808
NF-Category		61.71	12.80			
ST-Category	17	56.47	13.63	1.39	16	.184
NT-Category		45.71	22.65			
ST-Category	17	56.47	13.63	-1.08	16	.294
NF-Category		61.71	12.80			
NT-Category	17	45.71	22.65	3 07	16	.007
NF-Category		61.71	12.80			

As a final summary of the relationship between cognitive-based learning style (GEFT) and personality-based learning style (LPI), it was found that there was a significant negative correlation between GEFT and SF category style for males and a significant positive correlation between GEFT and SF category style for females. Depending on the pairs of category styles used for comparison, field-dependent subjects tended to be SF> ST, NF>NT. The SF>ST, NF>NT pattern was expected for field-dependent learners. This finding was fairly consistent between males and females. Field-independent subjects tended to be NF>SF, ST>NT. This pattern did not entirely match expectations for field-independent learners. In fact female field-independent subjects demonstrated the same learning styles, perception, and judgment terns as field-dependent females. Field-independent males more closely approximated expectations and demonstrated a different pattern than field-dependent males.

Relationships among Learner Characteristics and with Science Achievement

The relationships among the learner characteristics and between the learner characteristics and science achievement were explored using correlations and a step-wise regression analysis. It was originally decided to do the analysis across both genders prior to the discovery of the confounding effects of gender within the relationships between cognitive-based learning style and personality-based learning style. Therefore, further correctional and regression analyses were conducted for males and females separately. The small sample sizes for males and females place limitations on these analyses.

Table 9 summarizes the associations among prior conceptual knowledge (PCK), metacognitive awareness (MA), metacognitive self-management (MSM), cognitive style (GEFT), sensing-feeling (SF), sensing-thinking (ST), intuition-thinking (NT), intuition-feeling (NF), informal attitude inventory (IAS), and self-regulation (SR) and between these learner characteristics and science achievement (SK). The sample size for the analyses in this cluster was reduced to 101 Grade 6 (N=52) and Grade 7 (N=49) students composed of 51 males and 50 females because of missing attitude and self-regulation scores.

Table 9

Associations among Learner Characteristics and Science Achievement for combined Sample (N=101), Males (N=51) and Females (N=50).

	MA	MSM	GEFT	SF	ST	NT	NF	IAS	SR	SK
PCK	0.16	0.27**	0.32**	-0.06	0.06	0.13	-0.14	-0.10	0.23*	0.45**
M	0.26	0.30*	0.41**	-0.29	-0.04	0.30*	0.10	-0.10	-0.02	0.46**
F	*0.07*	*0.24*	*0.22*	*0.06*	*0.15*	*0.05*	*0.31**	*0.13*	*0.38***	*0.43***
MA		0.62**	0.31**	-0.09	-0.10	0.09	0.02	0.26**	0.24*	0.36**
M		0.49**	0.40**	-0.37**	-0.05	0.36**	0.15	0.10	-0.03	0.35*
F		*0.70***	*0.24*	*0.05*	*-0.13*	*0.13*	*-0.05*	*0.36***	*0.41***	*0.35**
MSM			0.21*	-0.03	-0.00	0.18	-0.13	0.14	0.25*	0.32**
M			0.24	-0.25	0.11	0.24	0.00	0.02	-0.05	0.33*
F			*0.20*	*0.12*	*-0.08*	*0.17*	*-0.21*	*0.21*	*0.46***	*0.30**
GEFT				-0.08	-0.10	0.10	0.10	0.03	0.20*	0.47**
M				-0.30*	-0.04	0.22	0.23	0.02	0.15	0.57**
F				*0.23*	*-0.16*	*-0.05*	*-0.06*	*0.05*	*0.30**	*0.38***
SF					-0.08	-0.66**	-0.44**	-0.24*	-0.01	-0.12
M					0.06	-0.70**	-0.55**	-0.41**	-0.27	-0.38**
F					*-0.22*	*-0.53***	*-0.24*	*-0.21*	*-0.01*	*0.03*
ST						-0.24*	-0.51**	-0.21*	-0.21*	-0.07
M						-0.38**	-0.46**	-0.19	-0.09	-0.17
F						*-0.14*	*-0.58***	*-0.23*	*-0.31**	*0.01*
NT							0.01	0.42**	-0.19	0.23*
M							0.17	0.49**	0.35*	0.48**
F							*-0.24*	*0.46***	*0.22*	*0.07*
NF								0.07	0.04	-0.03
M								0.19	0.15	0.15
F								*0.01*	*0.05*	*-0.14*
IAS									0.57**	0.06
M									0.65**	0.08
F									*0.51***	*0.02*
SR										0.38**
M										0.29*
F										0.41**

*denotes $p \leq 0.05$, **denotes $p \leq 0.01$

The correlation results are somewhat easier to comprehend if they are considered in four clusters. The first cluster is the internal correlations for the personality-based learning style inventory and the correlations between the two perspectives of learning styles reported earlier (Table 6) which will not be discussed here in detail. The second cluster is the correlations among the learner characteristics excluding the LPI variables. The third cluster involves correlations among attitudes, self-regulation, and LPI variables. The final cluster involves the correlations between learner characteristics and science achievement.

Exploration of the intra-LPI correlations clearly illustrates the differences between the perception modes. Both sensing styles (SF and ST) are significantly and negatively associated with the intuition styles (NF and NT). The associations between the judging styles (SF and ST or NF and NT) are not significantly correlated. This appears to indicate that perception is more influential than judgment in determining the LPI style. The most interesting results were the differences between males and females for SF vs ST, SF vs NT, SF vs NF, ST vs NT, and NT vs NF. These results were somewhat surprising since no gender differences were reported for the LPI. The correlations between the cognitive-based learning style and the personality-based styles clearly indicated gender differences. The magnitude and direction of the associations were drastically different for males and females; therefore, the correlations for the combined samples were neutralized.

The correlations among the learner characteristics (excluding the LPI variables) revealed a rather consistent significant association between pairs of variables, except for the associations between attitudes and prior conceptual knowledge (-0.10), metacognitive awareness and prior conceptual knowledge (0.16), attitudes and cognitive style (0.03), and attitude and metacognitive self-management (0.14). The other 11 correlations were significant at $p \leq 0.05$ Again, sizeable differences between the associations for males and females were found for PCK vs MA, PCK vs GEFT, PCK vs SR, MA vs MSM, MA vs GEFT, MA vs IAS, MA vs SR, MSM vs IAS, and MSM vs SR.

The sizeable correlation between metacognitive awareness and self-management indicates a large common variance predicted by the literature (Flavell, 1979; Garner, 1992).

Attitudes appeared to be poorly associated with most cognitive or metacognitive variables, except that attitude was significantly associated with metacognitive awareness. This potential association was detected in an earlier qualitative study (Craig & Yore, 1995). The significant associations between prior conceptual knowledge and metacognitive self-management support the assumption that self-directed learners more effectively construct and retain knowledge. The cognitive style results are supported by many other studies (Shymansky & Yore, 1980; Wiltkin, et al., 1977; Yore, 1986).

The surprising results involved the affective characteristic labeled self-regulation (SR). This factor includes a student's perception of success, effort, motivation and self-awareness. It requires further consideration since it appears to be similar to self-efficacy and appears to bridge cognitive, metacognitive, and affective dimensions. Furthermore, the gender differences in 9 sets of associations suggest that males and females may have different underlying relationships among learner characteristics.

The third cluster of correlations involved the LPI categories and the other variables. Only the NT category appeared to be consistently and positively associated with the other variables. These associations support the earlier assumption that field-independence and the NT style were closely associated, which was illustrated by these data for males but not for females. Both characteristics appear to be analytical and closely parallel the dispositions ascribed to science inquiry. The other associations need to be inspected for males and females separately. These data suggest that when females are given a choice to respond analytically or sensing and feeling, they will over-ride their analytical attributes in favour of their social-emotional attributes.

The final cluster of correlations involved the associations between learner characteristics and learning. Six of the 10 (60%) associations were significant; and when the four LPI variables are disregarded, five of six (83%) associations were significant. These findings support the assumption that cognitive or metacognitive learner characteristics are positive influences on science learning. The gender differences in this cluster were not as drastic, except for the associations among the LPI styles, self-regulation and science achievement.

A step-wise regression analysis was conducted to determine the order of significant loadings for the learner characteristics on predicting science achievement. The analysis of the combined males and females yielded the following regression equation for raw scores (the order of the terms reflects variance contributions):

SK **males and females** = .31GEFT + .61PCK + .39SR + .05MA + 1.73

All other learner characteristics (MSM, SF, ST, NT, NF, and IAS) did not make significant contributions to predicting science achievement for these subjects. The four learner characteristics entered into the regression equation accounted for 40.8% of the variance in science achievement. Cognitive style accounted for 22.4% of the variance, prior conceptual knowledge accounted for an additional 10.3% of the variance, self-regulation accounted for an additional 5.4% of the variance, and metacognitive awareness accounted for an additional 2.6% of the variance.

The step-wise regression analyses for males and females yielded drastically different equations. The regression equation for the males' raw scores was:

SK **males** = .48GEFT + .12NT + 6.79

This equation accounted for 45.6% of the variance. Cognitive style accounted for 32.5% of the variance, and intuition-thinking preference accounted for an additional 13.1% of the variance. The regression equation for the females' raw scores was:

SK **females** = .85PCK + .09MA + 5.59

This equation accounted for only 28.7% of variance. Prior knowledge (PCK) accounted for 18.1% of the variance, and metacognitive awareness (MA) accounted for an additional 10.6% of the variance.

Discussion and Implications

The interactive-constructive model of learning, which is consistent with the view that successful science learning involves constructing meaning from diverse information sources, served as the model for the present study. This model considers perception and processing of information and how prior knowledge, metacognition, task, and context influence the meaning construction process (Yore & Shymansky, 1991). This study explored the learner dimension in learning biological science topics in the context of regular elementary classrooms. The focus of the present study was the description of potential associations among learner characteristics and between learner characteristics and science achievement.

The results of the cognitive learning style assessment suggested that these Grade 6 and 7 students were primarily field-dependent. Both males and females demonstrated this tendency equally. In terms of personality-based learning style, these students may be described primarily as either sensing-feeling (SF) or intuition-feeling (NF) learners. The SF preference is seen to be consistent with the field-dependent tendency observed on the cognitive style measure. There were differences between males and females on the personality-based learning styles. Some males in this sample appeared to demonstrate perception, processing, and judging attributes more closely aligned with the analytical demands of science and science teaching. Most females and some males in this sample appeared to prefer and demonstrated field-dependence, sensing perception and feeling judgment, which do not appear to closely match the demands of science inquiry. Very few of the students demonstrated the intuition- thinking (NT) learning style that is most closely associated with academic success.

There was no clear pattern of relationships between cognitive-based learning style and personality-based learning style. While most of these students could be described as field-dependent and SF learners, both of which seem to be consistent with each other, gender differences appeared to confound the correlations. When field-independence and field-dependence were considered separately for males and females, the pairwise comparisons of personality-based learning style became somewhat clearer. Specifically, field-independent male students demonstrated an intuition-feeling (NF) >sensing-thinking (ST), intuition-thinking (NT) >sensing-feeling (SF) profile, and field-dependent males demonstrated sensing-feeling (SF) >intuition-feeling (NF), sensing-thinking (ST) >intuition-thinking (NT) profile, which were somewhat aligned with expectations. Both field-independent and field-dependent females demonstrated the same SF>NF, ST>NT profile that was somewhat consistent with expectations for a field-dependent person but not consistent with the expectations for a field-independent person. The interesting result is that field-independent females faced with a situation involving a variety of perception-judgment opportunities appeared to prefer options that are not aligned with their cognitive style. Females appeared to consistently prefer situations in which they can express their personality and perceive with their senses and judge with their feelings.

Associations between metacognition and conceptual knowledge were demonstrated. The impact of metacognition on science learning was further explored by comparing changes in conceptual knowledge for low and high levels of metacognitive awareness and metacognitive self-management (Holden, 1996). In all comparisons those students with high metacognitive awareness and metacognitive self-management made greater gains in conceptual knowledge than did those students with low metacognitive awareness and metacognitive self-management. Furthermore, post hoc analyses of these results demonstrated that male students showed stronger associations between conceptual knowledge and metacognition than did their female classmates. For female students all associations between prior conceptual knowledge and metacognition were weak. However, the results of science achievement analyses revealed interesting differences. Among the males, the correlations between science achievement and metacognition were reasonably unchanged from prior conceptual knowledge results. For females, the correlations between science achievement and metacognitive self-management remained unchanged. However, the association between science achievement and metacognitive awareness demonstrated an increase. This change in associations suggests that science instruction can influence female students' metacognition and cognition and formalize the linkages between metacognitive awareness, executive control, and science learning.

Cognitive learning style correlated significantly with prior conceptual knowledge, metacognitive measures, and science achievement. The field-dependent tendencies of many of the students in this study might negatively impact growth in conceptual knowledge, metacognitive awareness, and metacognitive self-management in the context of teaching environments that seem to favor field-independent and intuitive-thinking (NT) learners.

The NF style that best described the male students in this study showed moderate correlations between metacognitive awareness and metacognitive self-management. Thus it might be that the commonality between NF learning style and metacognition helped the male students. A similar explanation does not seem to hold for the female students who were predominantly sensory-feeling (SF). The SF learning style showed the weakest of associations with any of the conceptual knowledge and metacognitive variables.

Another avenue of explanation may lie with the findings on the informal attitude survey. Four of the 24 attitude items loosely labelled self-perception-regulation correlated significantly with both metacognitive awareness and metacognitive self-management. Thus, it might be that metacognition and conceptual knowledge are associated through this intermediary affective factor of self-perception-regulation. This disposition or habit of mind may be the link between metacognitive awareness (knowledge about strategies), metacognitive self-management (use of strategies), and achievement in science (conceptual growth).

There seems to be a need to investigate further the role played by attitude, especially that termed self-perception-regulation. In the present study this habit of mind correlated significantly with some of the conceptual and metacognitive measures. It seems that attitude is part of the broader metacognitive process, as some researchers have suggested. The affective disposition and habits of mind associated with science literacy (AAAS, 1993) appear to be closely aligned with metacognitive awareness and executive control.

This study found that the NT personality-based learning style was significantly associated with conceptual knowledge, metacognition measures, and the self-perception-regulation attitude factor. It may be that the NT learning style student, the self-regulated learner, the thoughtful expert reader of science textual material who is strategic, metacognitively aware, and able to exercise executive control are all the same. Future research needs to investigate more closely larger numbers of students who demonstrate preference for the NT learning style to determine how well they reflect the self-regulated metacognitive learner.

The entire issue of gender variations in the personality-based learning style for field-independent students needs further investigation. Males appear to utilize analytical cognitive styles that are closely aligned with the epistemology of science, while females rely on prior conceptual knowledge and metacognitive knowledge of the task. When these results are considered in combination with the self-regulation, metacognition and science achievement results, it may be speculated that explicit comprehension instruction and epistemic instruction embedded in the content of the nature, history, and philosophy of science and technology may have differential influences on Grade 6 and 7 females and males. Spence (1994) found significant improvements in metacognition and science reading comprehension for males and females when explicit comprehension instruction and guided inquiry were embedded in a nature of science and technology unit. Unfortunately, the sample size and experimental design did not allow gender differences to be explored.

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