# AC 2009-478: STUDENTS' COGNITIVE SELF-APPRAISAL AND SELF-MANAGEMENT, AND THE LEVEL OF DIFFICULTY OF AN ENGINEERING DESIGN PROJECT: ARE THEY RELATED?

**Oenardi Lawanto, Utah State University**

Oenardi Lawanto is an assistant professor in the Department of Engineering and Technology Education at Utah State University. He received his B.S.E.E. from Iowa State University, M.S.E.E. from University of Dayton, and Ph.D. from University of Illinois at Urbana-Champaign. Before coming to Utah State University, Dr. Lawanto taught and held several administrative positions at the Universitas Surabaya in Indonesia. His long years of teaching experiences in the area of electrical engineering have offered him new perspectives on teaching and learning. He has developed and delivered numerous workshops on student-centered-learning and online-learning-related topics during his service in Indonesia. Dr. Lawanto's research interests include cognition, learning and instruction, and online learning. Address: Department of Engineering and Technology Education – College of Engineering, Utah State University, Logan, UT 84322; email: olawanto@engineering.usu.edu.

**Scott Johnson, University of Illinois**

Professor Scott D. Johnson is Chief Information Officer and Associate Dean for Online Learning in the College of Education at the University of Illinois at Urbana-Champaign. He has been involved in technical education and human resource development for over 30 years as high school industrial arts instructor, a training consultant to industry, and as a teacher educator at the university level. His research and consulting activities address ways to improve the quality of technical instruction. Dr. Johnson specializes in instructional design, instructional methods, and online learning. He is a primary developer of HRE Online, a web-based system that supports the delivery of the department's online graduate program. He is also the Research Director for the 33 National Center for Engineering and Technology Education and co-director of the Academy for Excellence in Engineering Education. The focus of the Academy is to enhance the quality of instruction in the College of Engineering at the University of Illinois. He received his Ph.D. from the University of Minnesota. Address: College of Education – University of Illinois at Urbana-Champaign, Champaign, IL 61820; email: sjohnson@illinois.edu.

# STUDENTS' COGNITIVE SELF-APPRAISAL, SELF-MANAGEMENT, AND THE LEVEL OF DIFFICULTY OF AN ENGINEERING DESIGN PROJECT: ARE THEY RELATED?

## I. Introduction

Researchers have uncovered a close relationship between attributional beliefs, strategic learning, and achievement.[1, 2, 3] Although the findings contribute positively to educational practices, knowledge of how those attributional beliefs, strategic learning, and achievement are related in ill-structured, problem solving activities is still limited. Few of those studies provide in-depth information on the mental interaction between students' personal reflections about their knowledge states and abilities and the actual action that may take place during the problem solving activities. Furthermore, many of the studies involve working on hypothetical problems that do not reflect the authentic learning contexts that students may encounter in their classroom activities. Hypothetical problems are generally simple, and clear instructions lead to the solutions.

Because metacognition involves a cognitive dimension of evaluating one's knowledge and abilities[4], the context of the problem that students are to solve may influence the manner in which they use metacognitive abilities. Students' capability and confidence to solve a particular problem, and their subjective perception of the task-value may correlate with the actual planning, monitoring, and regulating during problem solving activity. Paris and Winograd[4] refer those students' personal judgment about their ability to meet a cognitive goal as students' cognitive self-appraisal, and their abilities to plan, evaluate, and make necessary adjustment and revision during their work as their cognitive self-management. This personal judgment may correlate to students' perception about the nature of the tasks (e.g., the task difficulty) they are about to engage in. Because metacognitive ability is believed to play an important role in a problem solving situation, especially when dealing with an ill-structured problem[5], any study focused on school-related problems will significantly benefit educational practices. Moreover, such studies will not only enhance our understanding about the mental interaction between students' personal reflections about their knowledge states and abilities and the actual executed action but also lead to development of principles of a practical theory that can serve as instructive models about conditions leading to successful processes of cognition and learning. The focus of this study was to evaluate relationship between students' perception about their personal self-appraisal and self-management as well as the level of difficulty of the design task they engaged in.

## II. Metacognition and Engineering Design

Although researchers offer many different definitions and models, metacognition remains a "fuzzy" concept because researchers classify any cognition that might have relevance to knowledge and thinking as a metacognition.[4] Researchers in cognition pose varying definitions of metacognition, many of which overlap. While Marzano et al.[6] simplified the definition of metacognition by explaining it as a state of awareness of our thinking, Cuasay[7] defined metacognition as a process by which the brain organizes and monitors its cognitive resources. As specific tasks are performed, individuals use this awareness to control what they are doing.

Looking at previous definitions, it is clear that metacognition is a fundamental tool that enables learners to take control of their own cognition. As a result, they tend to learn better.[8,9] Researchers also classify the features or components of metacognition differently. Flavell[7] stressed the phenomena of metacognitive knowledge that consists primarily of factors of person, task, and strategies. Paris and Winograd[4] offered a more comprehensive view in which metacognition is observed through two essential features of metacognition: cognitive self-appraisal and cognitive self-management. Furthermore, the knowledge about cognitive states and abilities is shareable among people[4] and influenced greatly by the social aspects of the situation. [9] These aspects include the affective and motivational characteristics of thinking. Like other knowledge, metacognitive understanding develops with age and experience[10] and is an ongoing process of progressing through deeper insights or realizations that, in turn, lead to awareness or conscious understanding of self as agent.[11] All of these theories have led us to a belief that metacognition plays an important role in human learning at any level (e.g., K-12, post-secondary, organizations) and for any knowledge domain (e.g., language, mathematics, technology, and engineering) to do all kinds of cognitive activities (e.g., reading, troubleshooting, case-study, engineering design).

This study used Paris and Winograd's[4] view of two essential features of metacognition: cognitive self-appraisal and cognitive self-management. The reason for using this particular framework was twofold. First, compared to Pintrich's[12] idea of metacognitive knowledge and control, Marzano's et al.[6] knowledge and control of self and process, and Flavell's[13] classification of person, task, and strategy, Paris and Winograd's framework[4] is simpler and has a distinct boundary between self-appraisal and self-management. All of the essential components of metacognition offered by Pintrich[12], Flavell[13], and others are included in Paris and Winograd's[4] cognitive self-appraisal and self-cognition. Second, this model places the learner as the central part of the metacognition issue. While Flavell[13] defined the factor of person to be any cognitive processors, learners or other individuals, Paris and Winograd[4] placed more focus on the learners themselves. As this study will evaluate a student's metacognition individually, it would be appropriate to adopt such a framework.

**A. Cognitive Self-Appraisal**

Self-appraisal in learning refers to learners' personal judgment about their ability to meet a cognitive goal. When electrical-computer engineering students are asked to design an 8-bit digital counter, they may immediately wonder if they have enough knowledge (i.e., declarative, procedural, and conditional knowledge) to respond to such task. Self-appraisal includes "judgments about one's personal cognitive abilities, task factors that influence cognitive difficulty or cognitive strategies that may facilitate or impede performance."[4, p. 17]

Self-appraisal has a motivational aspect. Students' motivational components, such as intrinsic goal orientation, self-efficacy, task value, and learning beliefs play an important role in self-directed learning. In this study, the self-appraisal aspect was identified by students' self-confidence and self-efficacy to solve one particular problem, and how students valued the problem to be solved. Students' self-confidence refers to performance expectation, and relates specifically to task performance. Self-efficacy includes judgments about students' ability to accomplish a task as well as their confidence in their skills to perform that task. Task value refers to students' perceptions of the design project in terms of interest, importance, and utility. These three motivational factors indicate personal reflections about students' knowledge states and abilities, and these self-judgments are deemed to be the forerunners of their actions.[4] If students judge themselves as having little knowledge and expectation for success in solving a problem, and place minimal value on the problems they are about to solve, they will likely expend little effort to work on the problem.

### B. Cognitive Self-Management

Self-management skill, which is often called executive control of behavior[14], refers to students' abilities to plan before they handle a task and make necessary adjustments and revisions during their work. Three skills are commonly used to indicate the presence of students' self-management: their ability to plan, regulate, and evaluate their learning. Planning involves activities such as setting goals, analyzing tasks, and selecting strategies to achieve specific goals. Regulating refers to the fine-tuning and continuous adjustment of learners' cognitive activities. Evaluating or monitoring refers to assessing learners' current knowledge state. Evaluating activities include tracking of learners' attention as they learn, and self-testing and questioning. Evaluating occurs continuously: before, during, and after a task. This cognitive self-management has direct implications for students' performance and subsequent instruction.[4] This study examined how students executed those three metacognitive self-regulatory tasks in engineering design activities.

Design is at the core of engineering practices[15] and it has been recognized as a highly complex activity that requires a considerable amount of knowledge beyond what is stated in the design problem. To complete engineering design tasks successfully, students are challenged to rely on their self-appraisal and self-management skills. Proficiency in exercising metacognitive abilities is one of the factors that distinguishes novices from experts[8], and is pedagogically valuable for students.[16] Experts monitor their own problem solving activities as they observe their solution process and the outcomes of their performance. [17]

## III. Method

### A. Research Questions

1. Is there any significant relationship between cognitive self-appraisal and self-management of engineering students while they were engaged in a design project?
2. Is there any significant relationship between a student's metacognition (i.e., cognitive self-appraisal and self-management) and the level of difficulty of the design problem?

## B. Study Participants and Context of the Design Activities

This quantitative study involved 60 teams or projects comprised of 168 engineering students at a large U.S. Midwestern university who participated in the Senior Design classes across three different engineering disciplines in the fall semester, 2007. Three professors participated in the study: one professor for each Senior Design class. In the Senior Design classes, these students were required to work in teams, and each team solved one design problem of their choice. This study also invited the course coordinator, who evaluated the proposed design projects to ensure that they met the requirements stated in the course syllabus and it was worth doing and doable within a semester.

The objective of the three Senior Design courses was to help senior engineering students transition into industry through self-chosen team projects. The courses required students to emulate the day-to-day life of a real engineering design environment. Students were expected to gain a variety of benefits from their ill-structured problem solving experience that required them to synthesize and apply the knowledge they had gained through their engineering courses, to work within certain constrains (e.g., time, budget), and to present their progress and results through oral and written communication with clients and their advising professors. There was one common learning objective across the three Senior Design courses. Students were expected to be able to solve typical commercial or industrial problems by implementing design stages that they had learned from their experience and other past courses.

All of the study participants engaged in intensive engineering design activities throughout the semester. The advising professors of the three Senior Design courses agreed that all tasks that the students engaged in were ill-structured problems with various levels of task difficulty. The advising professors evaluated the level of difficulty of design problems based upon ill-structuredness, complexity, and dynamicity as proposed by Jonassen.[18]

The students worked on a wide variety of design projects such as designing products that might satisfy individuals as their end-users, designing manufacturing systems/machineries used in industry; designing and building various instruments using a conventional micro controller chip, developing an electric circuit using silicon nitride membranes; database migration and building security and emergency response of a building using a 3-D virtual reality tool.

## C. Instrumentation

Two survey instruments were constructed and used in this study: Engineering Design Project Inventory (EDPI) and Rubric for Rating Students' Design Project (RRSDP). Due to the lack of availability of test instrument that is specifically designed to evaluate students' CSA and CSM in engineering design context, adoption with some modifications of two existing instruments that measure students' CSA and CSM were conducted for this study. EDPI is a 34-item self-reporting instrument designed to assess a student's self-appraisal and self-management of cognition while solving relatively large ill-structured problems. Students rated themselves on a 7-point Likert scale from not at all true of me to very true of me. The instrument is based on two metacognitive features introduced by Paris and Winograd.[4] Eighteen items of EDPI were taken from the problem-solving confidence scales of Problem Solving Inventory (PSI) developed by Heppner[19] and task-value, self-efficacy, and metacognitive self-regulation scales of the Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich, Smith, Garcia, and McKeachie[20] and the other 16 items were developed by the reseachers. Internal reliability coefficient of MSLQ motivation and learning strategies scales vary between .52 and .93; and internal reliability coefficient of PSI problem solving confidence is .85. These items were modified by rewording them in such a way that they enabled students as the respondents to focus on a particular problem. Three doctoral students who were knowledgeable in cognitive self-appraisal and cognitive self-management constructs read and made suggestions for the purpose of improving the EDPI instruments. EDPI was pilot-tested in various engineering courses similar to the senior-design course. The internal reliability coefficient of EDPI self-appraisal scales vary between .839 and .870, the internal coefficient of EDPI self-management scales vary between .553 and .733.

The EDPI consisted of 19 items that assessed students' self-appraisal of cognition and 15 items that assessed their self-management of cognition. Those 19 self-appraisal items assessed student self-confidence, self-efficacy, and task value. The self-confidence scale was defined as self-assurance while engaged in problem-solving activities[19] while the self-efficacy scale assessed students' ability to perform. The task value scale is associated with students' evaluation of how they think of the task. Task value refers to students' perception of the course material in terms of interest, importance, and utility. As for students' self-management of cognition, three parts of activities such as planning, monitoring, and regulating processes were evaluated. The planning process included activities such as goal setting and task analysis. Monitoring process included activities such as tracking a students' attention as they work on the problem, self-testing, and questioning. Lastly, regulating process refers to the fine-tuning and continuous adjustment of students' cognitive activities. Students were expected to complete EDPI within 15 minutes' time.

The Rubric for Rating Students' Design Project was used to evaluate the level of difficulty of students' design projects (LDDP). A Rubric for Rating Students' Design project (RRSDP) consisted of six indicators involving three variable attributes of problems[18]: ill-structuredness, complexity, and dynamicity. Ill-structured problems often possess aspects that are unknown[21] and they possess multiple solutions or solution methods.[22] Problem complexity is determined by the number of issues, functions, or variables involved in the problem, the degree of connectivity among those variables, and the stability among the properties of the problem over time.[23] The advising professors rated their students' LDDP on a 4-point Likert scale from few or low or unlikely (a score of 1) to many or high or likely (a score of 4).

The contents of both version of the EDPI instruments and the LDDP instrument were analyzed for their content and face validities. Two engineering professors also read and made suggestions to improve the LDDP instrument. Both EDPI and RRSDP were approved by the researchers' Institutional Research Board.

**D. Data Collection Procedures and Analysis**

Participation in the study was voluntary. Due to the sensitive nature of the data collected, no other identification was included in both survey instruments except for the last four digits of a student's university identification number (UIN). As soon as all data were entered into an SPSS program for data analysis, students' identifications were deleted and replaced with 3-digit numbers. Only the researcher had access to the data.

Because the survey instruments assess students' perception, which reflects their metacognitive experience, they must be completed as soon as any experiences with self-appraising and self-managing occur. The study participants were invited to complete the EDPI at the final stage of their engagement of the project. During the same time frame, the advising professors were requested to rate the level of difficulty of students' projects by completing the RRSDP. The data analysis process began as soon as all data were collected.

The results of this investigation were based on the data collected on all study participants who completed the EDPI and RRSDP. In order to facilitate analysis and discussion of the results, data from each instrument were reviewed separately and then combined to determine if any relationship existed. Data from each group of students (i.e., ECE, ME, and CS) were reviewed and analyzed separately. Because most students worked in a team, each team member received the same score for the RRSDP.

Hierarchical Linear Model (HLM) was used to evaluate any relationship between variables (research questions 1 and 2). Two-tailed Pearson Correlations between each subscale of students' self-appraisal of cognition and correlation between students' overall self-appraisal and self-management, as well as correlation between the two metacognitive features and level of design project difficulty were calculated using the standardized mean. Further, hierarchical linear regression[24] was conducted to investigate the relative importance of the contribution of each subscale of students' CSM.

## IV. Results

### A. Relationship Between CSA and CSM

In this investigation, the relationship between students' CSA and CSM was evaluated. A two-tailed Pearson correlation analysis indicated a significant correlation between CSA and CSM, $r(168) = .69$, $p < .01$. A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 1. This finding suggests that students' cognitive self-appraisal was significantly correlated with self-management.

A simple regression test was conducted to determine the relative importance of the contribution of each subscale of students' CSA (i.e., self-confidence, self-efficacy, task value) towards cognitive self-management. The results of the analysis revealed that task value ($\beta = .28$, $p = .00$) and self-confidence ($\beta = .28$, $p = .00$) were both highly significant predictors of the self-management score, and followed by self-efficacy ($\beta = .26$, $p = .02$). It is obvious from this simple regression test that, although task-value and self-confidence were ranked first as a significant predictor of students' CSM, the differences among these regression coefficients were quite small. The three subscales of self-appraisal constituted about 46 percent of overall students' self-management.

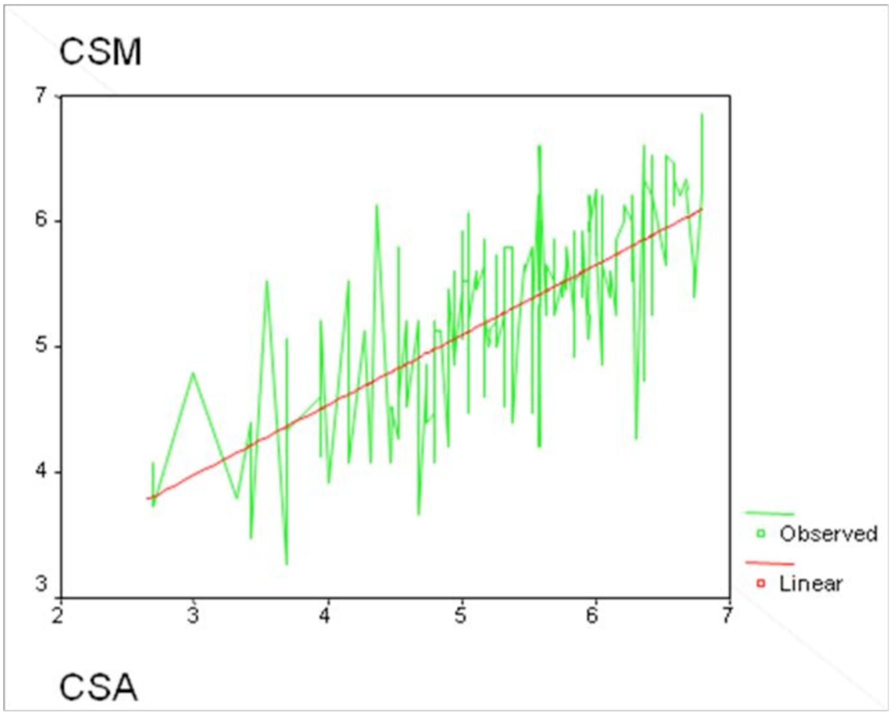


*Figure 1. Correlation between CSA and CSM*

**B. Relationship Between Metacognition and LDDP**

The possible existence of a significant relationship between metacognition and the level of difficulty of the design projects (LDDP) was evaluated through a correlation test. Through a frequency count, it was found that the LDDP of all students' design projects were normally distributed with a mean of 16.07 and a standard deviation of 3.20. A wide range of design difficulty was indicated among these design projects.

A two-tailed Pearson correlation test was conducted and no significant relationship was found between students' overall metacognition and the LDDP, r (168) = -.02, p > .05. Two Pearson correlation tests were conducted to evaluate the possible existence of a significant relationship between CSA and the LDDP, and between CSM and the LDDP. The finding suggests that there was no significant relationship found between the two metacognitive features and the LDDP. (Table 1 and Table 2).

| | Test components | Rate |
|---|---|---|
| CSA | Pearson Correlation | -.031 |
| | Sig. (2-tailed) | .693 |
| | N | 168.000 |

Table 1. Correlation Between CSA and LDDP

| | Test components | CSA |
|---|---|---|
| CSM | Pearson Correlation | .011 |
| | Sig. (2-tailed) | .885 |
| | N | 168.000 |

Table 2. Correlation Between CSM and LDDP

## V. Conclusions & Discussion

### A. Cognitive Self-Appraisal and Cognitive Self-Management are Closely Related.

Results of bivariate correlation tests revealed the existence of a significant relationship between cognitive self-appraisal (CSA) and cognitive self-management (CSM) of engineering students while engaged in the design project. The results of these tests indicated the presence of a high correlation of both significance values, p, and correlation coefficients, r. The findings confirm the relationship between students' developmental attribution beliefs and strategic knowledge highlighted in numerous studies.[1,3,9,25]

Paris and Winograd[4] argued that two essential features of metacognition (i.e., self-appraisal and self-management of cognition) capture the information processing account of declarative and procedural knowledge. While self-appraisal includes personal reflection about one's knowledge and abilities, self-management refers to how self-appraisal is put into action. In this study, a significant relationship was found between CSA and CSM in the three groups of engineering students at the final stage of their engagement in senior design projects. Students with a low CSA had a low CSM, and vice-versa. In other words, students' awareness of knowledge states and abilities impacted the way they planned, monitored, and made necessary adjustments. Chan and Moore[1] argued that students who were taught cognitive and metacognitive strategies for learning along with attempts to convince students to attribute success and failure to effort and effective or noneffective use of strategies can succeed in breaking the vicious cycle of entrenched, learned helplessness belief and their negative impacts on learning strategies and academic achievement. Another study conducted by Chambres, Bonin, Izaute, and Jean-Marescaux[9] found that even a fictitious position of expertise promotes metacognition and student effectiveness. For instance, students randomly said to be experts in English performed better than those said to be nonexperts.

The significant relationship between students CSA and CSM that was found in this study did not imply a causal relationship. Rather, the findings indicated that the two metacognitive features are interdependent. In other words, the statistical tests employed in this study were not meant to determine any causal conclusions. Specifically, the findings showed that when students feel that they have the adequate knowledge, ability, and interest to solve the design problems, they are more likely to be motivated to engage in the problem successfully through adequate planning, monitoring, and making necessary adjustments in their thinking. This finding and other similar findings in Chan and Moore[1] and Chambres's et al.[9] studies indicate the need of enhancing students' self-appraisal to produce better cognitive self-management while engaging in an engineering design project.

**B. Students' Metacognitive Abilities do not Relate to the Level of Difficulty of the Design Project.**

Statistical results revealed no significant relationship between the variables of students' metacognition and the level of difficulty of the design project (LDDP). The researchers first evaluated the relationship of the two variables by looking at all students as a single sample population. From the statistical tests, no correlation was found between overall students' metacognition and LDDP. In addition, no significant relationships were found between students' CSA and the LDDP, nor between students' CSM and the LDDP. Similar results were also found when correlation tests were conducted for each individual group of student samples. From those several correlation tests, no significant relationships between the two variables were found.

The absence of any significant relationship between the two variables is inconclusive. This may be due to two influencing sources: factors internal to the students and an outside agent's determination of problem difficulty. Internal factors may involve students' lack of experience in predicting the complexity of their design projects, overconfidence, and trial-and-error working tactics. Because of these factors, students may not anticipate the unexpected during the project. The determination of problem difficulty by the professors may also be the influencing source of the absence of significant relationship between students' metacognition and LDDP. Students' metacognition and the level of problem difficulty were evaluated by two different groups of individuals. The two groups of individuals may perceive the level of difficulty of the design problem differently. Therefore, their judgments regarding the level of difficulty of the design problem may vary. Consequently, the results of the correlation tests conducted may not show the real relationship between students' metacognition and LDDP.

## VI. Recommendations

### A. Recommendation for Engineering Design Educators

From this study and previous studies about students' metacognition, it is apparent that there is a significant relationship between one's CSA and CSM. Although this study only confirmed the existance of the relationship between CSA and CSM, and also self-efficacy, self-confidence, and task value contribute less than 50 percent of overall students' self-management, it is strongly suspected that these three self-appraisal factors may have played an essential role in shaping students' self-management. It is therefore, students may need to devote time to thinking and discussing their design tasks with their teammates or instructors, especially at the earlier stage of the project. Issues that may relate to students' self-appraisal and self-management isssues may be discussed to smooth the design process at the later design stages.

### B. Recommendations for Researchers in Engineering Education

Two recommendations are offered for future research. First, this study has offered some insight into how students' metacognition is used in an engineering design project; however, due to the limited number of student participants employed in this study, researchers may want to conduct a similar study that involves a larger number of engineering study participants from several colleges and universities. Inviting students to evaluate the level of difficulty of their own design project may need to be considered so that the level of metacognition and difficulty of the problem are both based on students' perceptions. A similar study that involves ill-structured problems and other types of problems with various levels of difficulty in other fields of engineering and sciences may also need to be considered to improve the generalizability of the findings and our understanding about the use of metacognition in solving ill-structured problems.

Second, a follow-up study may be conducted to further our understanding about the relationship between metacognition and students' design performance. Although there are numerous existing studies that investigate how metacognition impacts performance, similar studies may focus on the investigation about how each of the components of the self-appraisal and self-management from various groups of engineering students relate to design performance. A standard method of assessing students' design performance needs to be formulated to increase the validity of the data.

## References


1. Chan, L. K. S., and Moore, P. J. 2006. Development of attributional beliefs and strategic knowledge in years 5 to 9: A longitudinal analysis. Educational Psychology 26(2): 161-185.
2. Graves, D. H. 1983. Writing: Teachers and children at work. Portsmouth, NH: Heinemann Educational Books.
3. Ross, M. E., Green, S. B., Salisbury-Glennon, J. D., and Tollefson, N. 2006. College students' study strategies as a function of testing: An investigation into metacognitive self-regulation. Innovative Higher Education 30(5): 361-375.
4. Paris, S. G., and Winograd, P. 1990. Metacognition in academic learning and instruction. In Dimension of thinking and cognitive instruction, ed. B. F. Jones, 15-44. Hillsdale, NJ: Erlbaum.
5. Hong, N. S., Jonassen, D. H., and McGee, S. 2003. Predictors of well-structured and ill-structured problem solving in an astronomy simulation. Journal of Research in Science Teaching 40(1): 6-33.
6. Marzano, R. J., Brandt, R. S., Hughes, C. S. Jones, B. F. Presseisen, B. Z., Rankin, S. C., and Suhor, C. 1988. Dimensions of thinking: A framework for curriculum and instruction. Alexandria, VA: Association for Supervision and Curriculum Development.
7. Cuasay, P. 1992. Cognitive factors in academic achievement. Higher Education Extension Service 3(3): 1-8.
8. Bransford, J., Brown, A., and Cocking, R. 1999. How People Learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.
9. Chambres, P., Bonin, D., Izaute, M., and Marescaux, P.J. 2002. Metacognition triggered by social aspect of expertise. In Metacognition Process, Function and Use, eds. P. Chambres, M. Izaute, and P.J. Marescaux, 153-168. Norwell, MA: Kluwer Academic Publishers.
10. Garner, R., and Alexander, P.A. 1989. Metacognition: Answered and unanswered questions. Educational Psychologist 24: 143-158.
11. McCombs, B, L., and Marzano, R. J. 1990. Putting the self-regulated learning: The self as agent in integrating will and skill. Educational Psychologist 25(1): 51-69.
12. Pintrich, P.R. 2002. The role of metacognitive knowledge in learning, teaching, and assessing. Theory into Practice 41(4): 219-225.
13. Flavell, J. H. 1979. Metacognition and cognitive monitoring: A new area of cognitive developmental inquiry. American Psychology 34: 907-911.
14. Paris, S. G., Lipson, M., and Wixson, K. K. 1983. Becoming a strategic reader. Contemporary Educational Psychology 76: 1239-1252.

15. Dieter, G. E. 1983. Engineering Design. New York: McGraw-Hill.
16. Leonard, W.J., Dufresne, R.J., and Mestre, J. P. 1996. Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems. American Journal of Physics 64: 1495-1503.
17. Glaser, R. 1992. Expert knowledge and processes of thinking. In D. Halpern (Ed.), Enhancing Thinking Skills in the Sciences and Mathematics (pp. 63-75). Hillsdale, NJ: Erlbaum.
18. Jonassen, D. H. 2004. Learning to solve problem. San Francisco, CA: Wiley.
19. Heppner, P. P. 1988. The problem-solving inventory: Manual. Palo Alto, CA: Consulting Psychologists Press.
20. Pintrich, P. R., Smith, D. A. F., Garcia, T., and McKeachie, W. J. 1991. A Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ). University of Michigan.
21. Wood, P. K. 1983. Inquiring systems and problem structures: Implications for cognitive development. Human Development 26: 249-265.
22. Kitchner, K. S. 1983. Cognition, metacognition, and epistemic cognition: A three-level model of cognitive processing. Human Development 26: 222-232.
23. Funke, J. 1991. Solving complex problem exploration and control of complex systems. In Complex Problem Solving Principles and Mechanism, eds. R. J. Sternberg and P. A. Frensch, 185-222. Mahwah, N.J.: Erlbaum.
24. Elazar, J. P. 1997. Multiple regression in behavioral research. New York: Wadsworth.
25 Jonassen, D., Strobel, J., and Lee, C. B. 2006. Everyday problem solving in engineering: Lessons for engineering educators. Journal of Engineering Education 95(2): 139-151.