2006-876: DEVELOPING METACOGNITIVE ENGINEERING TEAMS THROUGH TARGETED WRITING EXERCISES AND STUDYING LEARNING PREFERENCES

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Impact of Structured Writing and Awareness of Cognition on Effective Teaming

Abstract

Metacognition is the awareness and understanding by a student of his or her own learning own skills, performance, preferences, and barriers. This paper describes a pilot scale effort to develop metacognition in engineering teams at Rowan University through structured writing and the use of the Learning Connections Inventory (LCI). The theoretical basis for the LCI is the Interactive Learning Model, which proposes that learning processes occur through four distinct learning patterns: sequential, precise, technical, and confluent. The LCI was used to profile the learning style of each student in the Rowan Chemical Engineering department.

During the Fall Semester of 2004, engineering teams in the Junior/Senior Engineering Clinics were broken into four categories. Category I teams received instruction in use of the LCI and met with a facilitator and their teammates to examine their LCI profiles. In this meeting, potential areas for future conflict were discussed and the teams developed strategies to avoid these conflicts. Category II teams received no LCI instruction but participated in a series of structured writing assignments designed to enhance their awareness of teaming. These assignments included developing and ratifying a team charter and submitting biweekly reports on barriers to success and team dynamics. Category III teams received both the LCI training and participated in the structured writing assignments, while Category IV teams served as a control and participated in none of the activities.

At the beginning of the semester, each person was surveyed to determine their perception of their teaming skills, their opinion of teams, and their level of interest in learning about teaming. The participants were surveyed again at the end of the semester and were also asked to evaluate the usefulness of the strategies. In addition, final project reports were collected and evaluated using a system of rubrics in order to assess the impact of these activities on team performance. The data indicate that the students receiving LCI instruction (with or without the targeted writing exercises) both performed better, and had better attitudes towards teaming, than did the students receiving no LCI training. There was also some indication that the targeted writing exercises were beneficial but these results were less conclusive.

Background and Pedagogical Theory

Behavioral scientists classify thought processes into cognitive and affective domains[1]. The cognitive domain includes higher order thought processes such as logic and reasoning and is the primary (and in many cases, the only) target of engineering curricula. The affective domain includes attitudes, values, and self-concept. These attributes typically cannot be measured directly through exams and other classroom instruments, yet they are essential components of the overall developmental process.

ABET itself recognizes the importance of the affective domain by including criteria in their assessment of engineering programs such as "engages in lifelong learning," "understands the impact that engineering has on society," and "communicates effectively"[2]. Besterfield-Sacre *et al*. observed that students' attitudes about engineering and their abilities change throughout their education and influence motivation, self-confidence, perception of engineering, performance, and retention[3]. The same group also found that attitudes toward engineering directly related to retention during the freshman year[4]. Seymour and Hewitt[5] examined students who left engineering programs and found that according to measures *external* to the engineering curriculum (high school GPA, SAT scores, IQ, etc.) they were not academically different from their peers who continued in the program. Retention did, however, correlate closely with student attitude. For many students, college challenges their level of motivation and academic aptitude for the first time, but too often provides them with little or no help in identifying and overcoming the barriers to their learning.

The Study Group on the Conditions of Excellence in American Higher Education stated "there is now a good deal of research evidence to suggest that the more time and effort students invest in the learning process and the more intensely they engage in their own education, the greater will be their satisfaction with their educational experiences, their persistence in college, and the more likely they are to continue their learning"[6]. Thus, it is reasonable to conclude that an effective student must be both self-aware and self-directed, yet these issues are often ignored completely by engineering faculty.

Student awareness and understanding of their learning skills, performance, preferences, and barriers is referred to as metacognition. Although different research groups emphasize different aspects of metacognition[7], it clearly refers to two distinct, but related issues[8]:

- Awareness and knowledge of self as learner
- Conscious self-control and self-regulation of cognition

In essence, a metacognitive learner must understand his or her strengths and weaknesses in learning and consciously control how he or she will approach a problem. Weinstein and Meyer[9] described the importance of students' understanding their own learning preferences, abilities, and cognitive styles, and discussed how "learning how to learn" helps students develop knowledge of strategies required to achieve specific tasks. To provide this metacognitive awareness to our students, we used the Learning Connections Inventory (LCI), a survey instrument developed by Johnston and Dainton to profile an individual's learning patterns[10]. The theoretical basis for the LCI is the Interactive Learning Model, which posits that learning processes occur through four distinct learning patterns: sequential, precise, technical, and confluent. The patterns are used by all learners to varying degrees; a given individual's LCI profile is determined by the strengths of their preferences and avoidances, scored as "avoid," "use as needed," and "use first." Some learners lead with one or two patterns, some avoid certain patterns, some are able to use a number of patterns on an as-needed basis, and still others exhibit strong preferences for a number of patterns. Each pattern is distinguished by a number of features. A few hallmarks are listed below:

- **Sequential** learners prefer order and consistency. They want step-by-step instructions, and time to plan, organize, and complete tasks.

- **Precise** learners thrive on detailed and accurate information. They take copious notes and seek specific answers.
- **Technical** learners like to work alone on hands-on projects. They enjoy figuring out how something works and insist on practical objectives for assignments.
- **Confluent** learners have a strong desire for creativity and innovation. They are not afraid of risks or failure and prefer unique, unconventional approaches.

Depending on the interaction of an individual's patterns, strong preferences associated with one pattern may coincide with strong avoidances of another pattern. For example, the sequential learner's preference for order and consistency may be evidenced as a desire for predictability, and, therefore, as a corresponding avoidance of the risk and openness to chaos that is a characteristic of the confluent learner. In each case, knowledge of this profile provides extremely useful insights into the conditions that promote learning. The LCI is based on three assumptions about these conditions:

1) Learners learn most efficiently and successfully when allowed to use their stable-over-time patterns of cognition (intelligence, aptitude, experiences, levels of abstraction), conation (pace, autonomy, natural skills), and affectation (sense of self, values, and range of feelings) to engage in a learning task;

2) Learners learn best when given the opportunity to know their learning process, allowed to negotiate their learning environment, and provided the tools to strategize to meet the rigors of standardized and alternative methods of assessment and performance;

3) Learners receive the most effective instruction when their teachers have an appreciation for their diverse learning characteristics[10].

Other attempts to gain a better understanding of engineering students as learners have employed the concept of learning styles, using instruments such as the Myers-Briggs inventory[11,12]. The developers of the LCI explain the difference between their approach and that of learning styles in this way:

> Unlike learning styles, the Interactive Learning Model is an advanced learning system that provides an inward look at a learner's internalized metalearning behaviors, an outward analysis of a learner's actions, and a vocabulary for communicating the specific learning processes that yield externalized performance. Other measures of personality, multiple intelligences, or learning styles provide information about the learner and then leave the learner informed but unequipped to use the information. [The LCI] not only provides the learner with the means to articulate who s/he is as a learner, but then provides the strategies (metawareness) for the learner to use these learning tactics with intention.[13]

The LCI survey is composed of 28 Likert scale items—descriptive statements followed by a five-point set of responses—and three questions requesting written responses. The 28 questions are scored according to the patterns they illustrate, and from these scores the LCI profile is generated. The three written responses are used to validate the preferences and avoidances exhibited by the scores. Over the past 10 years, teachers and administrators in 11 national and international sites, along with faculty at Rowan University, have tested the reliability and validity of the LCI[10,13].

The project described in this paper attempts to integrate a metacognitive approach to learning with a basic component of engineering education: working in teams. Experts agree on the importance of involving undergraduates in teamwork[14-16]. Seat and Lord[17] observed that while industry seldom complains about the technical skills of engineering graduates, industrial employers and educators are often concerned with performance skills (i.e., interpersonal, communication, and teaming). Lewis *et al.*[18] correctly observed that if students are to develop effective teaming skills, then teaming must be an explicit focus of the project. A metacognitive approach would encourage students to become conscious of their team skills. Thus, metacognition may be valuable for improving an individual's relationship not only to their own learning processes, but also to the learning processes of others and to the collaborative learning process in general.

The LCI has been used in the engineering program at Rowan University to enhance the performance of student teams[19]. In Sophomore Clinic I, a multidisciplinary sophomore design and composition course that is taught collaboratively by faculty from engineering and composition and rhetoric, faculty used the results of the LCI to form teams with balanced components of each learning pattern, based on research suggesting that successful learning in team environments occurs if team members have complementary learning patterns.

Our hypothesis was that this particular combination of avoidances and preferences leads to barriers that specifically impact performance of student teams in the upper-level design courses, such as the Junior/Senior Clinics[20]. In these courses, students work independently in teams on semester-long and sometimes multi-year projects. Many of the projects involve external funding, real clients and sponsors, and actual product development. For example, student teams under the supervision of chemical engineering faculty have worked on emerging topics including enhancing the compressive properties of Kevlar, examining the performance of polymer fiber-wrapped concrete systems, advanced vegetable processing technology, metals purification, combustion, membrane separation processes and other areas of interest. Every engineering student participates in these projects and benefits from hands-on learning, exposure to emerging technologies, industrial contact, teamwork experience and technical communication practice[21,22].

These conditions make the Junior/Senior Clinics meaningful and exciting learning experiences, but the pressure derived from the intense and often unpredictable environment exacerbates the students' barriers to learning. Preferences for sequence and avoidance of chaos and risk leave some students frustrated by what they see as the lack of structure of a real-world project. They are unsure how to cope in situations where clear instructions and step-by-step procedures have been replaced by multi-tasking, frequent shifts in direction, uncertain timelines, and inconsistent expectations. They may become impatient with learning patterns exhibited by team members that conflict with their own. The situation is further compounded by the high technical preference that many of them have, which in addition to the hands-on, problem-solving aptitudes listed above, has other significant hallmarks. Although the technical learner is distinguished by a love of challenges, which serves the Junior/Senior Clinic student well, he or she is also known for preferences that are not so compatible with this situation: working alone, keeping knowledge and/or feelings inside, and resisting changes to familiar or preferred patterns. These students are not likely to naturally communicate regularly with team members, nor reflect on or seek guidance about obstacles they are experiencing. Of particular interest to us is the technical learner's resistance to writing. Because technical learners tend to value personal knowledge but tend to feel no need or desire to share that knowledge, they tend to write minimally.

An overwhelming majority of engineering students show preferences for technical learning. Of the more than 100 engineering students and professors who submitted LCI results, only two had an avoidance of technical (including one of the authors of this paper). While most teams were similar in their use of the technical learning pattern, they range widely in the other three categories.

This situation is addressed by using writing to harness the metacognitive awareness yielded by the LCI. In large part because of what we know about technical learners and their particular barriers, we believe that focusing on writing will be a productive approach on multiple levels:

- To see that students get increased opportunities to write in their classes, both in order to communicate and in order to aid learning

- To develop further the leadership skills faculty need to sustain long-term writing across the curriculum projects and the evaluation and assessment skills they need to determine these projects' effectiveness[23]

The perspective available from the LCI is used to target the specific barriers to student learning that have been identified.

Methodology

During the Fall Semester of 2004, the twelve Junior/Senior Engineering Clinic teams supervised by Rowan chemical engineering faculty were broken into four categories. Category I teams took the LCI survey and then the full team met with a facilitator to review the results. In this meeting, potential areas for future conflict were discussed and the teams developed strategies to avoid these conflicts. Category II teams received no LCI instruction but participated in a series of structured writing assignments designed to enhance their awareness of teaming. These assignments included developing and ratifying a team charter and submitting biweekly reports on barriers to success and team dynamics. Category III teams received both the LCI training and participated in the structured writing assignments, while Category IV teams served as a control and participated in none of these activities. In all, 32 chemical engineering students and five students from other engineering disciplines were involved in the study.

The students in categories I and III met with Dr. Kevin Dahm and Dr. James Newell during the first weeks of clinic to discuss their LCIs and those of their team members. Drs. Dahm and Newell are both chemical engineering faculty members who devised the methodology for this project in conjunction with the creators of the LCI. The meetings included discussion of the strengths and weaknesses of each preference, possible sources of conflict, and consideration of how different people process information and approach problems, and ways to bridge differences in learning preferences. As a specific example, when most members of a team have strong preferences for sequence (like most participants in this study) but one member avoids sequence, the high sequence team members would likely view the other learner as lazy or a procrastinator. At the same time, the sequence-avoidance learner would view the rest of his/her team as anal retentive and bossy. Recognizing the potential for this conflict in advance and understanding its cause can help teams deal with it more effectively when it happens, or avoid it entirely.

Because of the likelihood that team profiles are not balanced, students were counseled on the barriers presented by strong preferences for the technical learning pattern, so that team members would begin to fill the gaps created by lack of diversity. Technical learners prefer to dive in to hands-on work and are less likely to read directions or perform a comprehensive literature review first. While having technical learners is beneficially in the lab, someone needs to do the background work first. Groups with all technical learners were encouraged to appoint a member to start the literature review first, even though this meant working against their preferred pattern.

Category II and III teams produced bi-weekly status reports and team charters. Most faculty members, in supervising a clinic project, require some sort of periodic progress report or update. However, historically, there has been little coordination between faculty concerning the scope and format of these status reports. In the Fall 2004, faculty members supervising teams from Categories II and III required each member of each clinic team to answer the following questions, in the form of a written status report, every two weeks:

1. What issues are you having with the technical aspects of the project?

2. What logistical issues (ordering problems, scheduling, software issues, etc.) are you facing?

3. What issues in team dynamics have arisen since our last meeting and how are you dealing with them?

4. What do you think the highest priority task is during the next two weeks?

5. What is the largest barrier to accomplishing that task?

These questions resemble the journaling activities used at Clemson University[24] and the University of Texas at Austin[25] in which students write reflective pieces summarizing key concepts, discuss concerns, and (at UT Austin) create an analogy for the presented material. The five questions are intended to make the student focus on barriers to completing the project, team dynamic issues, and prioritization. They represent an effort to have the student evaluate not only whether his/her team has made suitable progress, but also what issues are creating problems. An additional goal is to help students avoid hierarchical judgments and focus instead on what made their teams effective or ineffective. While all teams in categories II and II submitted these memos, whether and how they were graded was the decision of the faculty supervisor of the project. In most cases the questions were not graded (other than ensuring that they were submitted), but served as the basis for discussion in the ensuing meeting.

Also during the first week of the semester, each team in Categories II and III was asked to develop and sign a team charter that dealt with specific issues in team dynamics including the role of each individual, the responsibility of each individual to the team, the responsibility of the team to each individual, and an algorithm for dealing with potential future conflicts.

Beyond the specific goals of the targeted writing exercises for this project, writing throughout the engineering curriculum has intrinsic benefits of its own. Kranzber[26] reported that, for engineers who had been out of school for ten years, the most common answer to the question "What courses do you wish you had taken?" was English or writing courses. Both ABET and the Canadian Accreditation Board[27] now require the development of communication skills for engineering students. As a result, many engineering programs incorporate writing-to-learn in their curricula[28,29]. The ability to formulate a coherent written report requires that the student think clearly about the technical engineering problem[29-32]. In much the same way, requiring students to contemplate, in writing, their approach to problem solving and the barriers that they are facing will compel the same clarity of thought. This clarity is an essential component of metacognition.

Results and Discussion

To evaluate the impact of the activities outlined above and the differences between students in categories I-IV, student attitude and performance were both measured. To objectively measure performance, the Jr/Sr Clinic final reports were evaluated using a set of rubrics that have been published in *Chemical Engineering Education*[33]. No faculty member evaluated his own team. Although these rubrics focus on demonstrating specific learning objectives, they are presented to students in terms of grades to help them better relate. A sample rubric is shown below:

Area: Technical Awareness

The A-team:

- Clearly demonstrates an awareness of the works of others and establishes a context for their project
- Identifies and understands works from multiple literature sources

The B-team:

- Shows some understanding of the work in the field, but has limited depth and breadth.
- Understanding is limited to faculty-provided materials

The C or lower – team:

- Fails to demonstrate an awareness of the works of others and the significance of their project

The average performance of the teams in each of the four categories was quantified as a GPA, as follows: An "A" level performance for a specific objective was assigned a score of 4, a "B" level performance a score of 3, etc. Table 1 below summarizes the average results for the teams in each Category with respect to each objective. The "Overall Evaluation" is the average score for teams with respect to all objectives, weighted equally. With only twelve teams total, the sample sizes were too small to achieve statistical significance. The results, however, do indicate that teams that received LCI training only (Category I) and teams that received both LCI training and structured writing assignments (Category III) performed better than those who received only structured writing assignments (Category II) and those who received no teaming training (Category IV) in all five rubric areas. No differences were found between teams receiving LCI training only (Category I) and teams receiving both LCI training and structured writing (Category III) in overall evaluation, meaningful errors analysis, proposed future work, or appropriate conclusions.

Table 1. Average performance of teams in Categories I-IV.

Rubric Topic	Category I LCI-Training Only	Category II Structured Writing Only	Category III Both LCI and Writing	Category IV Neither LCI nor Writing
Overall Evaluation	3.9	2.9	3.8	2.6
Technical Awareness	4.0	3.0	3.3	2.6
Proposed Future Work	3.7	2.8	4.0	2.0
Meaningful Error Analysis	3.7	2.5	3.5	3.0
Appropriate Conclusions	4.0	3.0	3.8	2.3

To examine how the project affected team attitudes, all students on participating teams were given a survey at the beginning and end of the semester. The results of this survey are summarized in Table 2.

Table 2. Comparison of Survey Results Given to Students before (Pre) and After (Post) Cognitive Awareness Exercises

Question (5 = Strongly Agree; 1 = Strongly Disagree)	Time	Category I LCI-Training Only	Category II Structured Writing Only	Category III Both LCI and Writing	Category IV Neither LCI nor Writing
I would like more training in dealing with team dynamics	Pre	2.25	2.33	2.60	2.25
	Post	3.25	3.00	4.10	2.50
I have received training in working effectively in teams	Pre	1.25	1.66	1.60	1.66
	Post	3.75	2.33	4.00	1.33
Learning to work effectively in teams is important	Pre	3.50	3.33	3.40	3.00
	Post	4.25	3.66	4.40	3.33
I prefer working with a team to working alone	Pre	1.75	2.00	1.80	2.33
	Post	3.00	2.66	2.60	2.33
Personality conflicts are a major problem with teams	Pre	4.00	3.66	3.60	3.66
	Post	3.50	3.66	3.00	3.33
Working on teams has helped me learn things about myself	Pre	2.25	2.66	2.00	2.33
	Post	3.50	3.00	3.60	2.00
I felt more comfortable working in teams this semester	Post Only	4.75	4.00	4.75	3.33

Teams that received LCI training only (Category I) and teams that received both LCI training and structured writing assignments (Category III) showed significant improvement in their attitudes regarding the importance of teaming skills during the course of their semester. A series of paired sample t-tests applied to the responses showed that for the students in Category I, the differences in responses to the pre- and post-semester surveys were statistically significant ($p<0.01$) for the questions "Working on teams has helped me learn things about myself," "I have received training in working effectively in teams" and "I prefer working on a team to working alone." For the students in category III, the change was statistically significant for the questions "I have received training in working effectively in teams," "I would like more training in dealing with team dynamics" and "Learning to work effectively in teams is important." For all other questions attitude did improve from pre- to post-semester survey but the differences were not statistically significant. Category I and II students also responded to the question "I felt more comfortable working in teams this semester" than did their classmates in Categories II and IV.

No significant differences ($p>.05$) were found between teams receiving LCI training only (Category I) and teams receiving both LCI training and structured writing (Category III). Teams that received neither LCI instruction nor structured writing exercises showed no significant changes ($p>.05$) in their opinions in the pre-semester and post-semester surveys.

Student teams were also surveyed to determine their opinion of the items (team charter, LCI, bi-weekly memos) used to improve their teaming skills. Nearly 75% of the students indicated that writing the team charters was a useful experience though 90% also said that they never referred to them again during the year. It appears that once all of the members agreed to a set of rules, they largely followed them. Most of the team charters focused on logistics: how frequently teams would meet, processes for notification if a meeting would be missed, and penalties for missing too many meetings. Few really examined the responsibilities of the team to the individual or the individual to the team (beyond all members must show up and do their assigned tasks).

In the year-end survey, the students unanimously disliked the bi-weekly memos, indicating they were a waste of time and not helpful. This was a surprising result in that all semester, the authors had received anecdotal feedback indicating that the memos were valuable. Faculty members indicated that the memos were a useful tool in identifying problems before they got out of hand. Further, all but one team from Categories I, II and III reported that their projects had been more successful this year than last, and both faculty and students indicated that there were no significant team dynamics problems in any of the teams in Categories I, II or III.

Summary

In an attempt to teach students to take a metacognitive approach to team projects, two activities were devised: use of the LCI to team students about their own learning preferences, and targeted writing exercises intended to promote focused reflection throughout the semester. A control experiment was designed to assess the impact of these two activities used individually or together. The results indicated that teams receiving the LCI training performed better than teams that did not, though sample sizes were insufficient to draw statistically significant conclusions concerning how the LCI and writing exercises affected team performance. A survey given at both the end and beginning of the semester demonstrates that the use of the LCI had a clear positive impact on the attitude of students towards teaming; these results were statistically significant. The impact of the targeted writing exercises is less clear: there were indications that these exercises have some value, but they were not popular with students. The authors concluded that these activities should be continued but that faculty must do a better job up front of explaining the rationale and benefits of the writing assignments to the students.

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