

## Developing Metacognitive Engineering Teams

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### Background and Pedagogical Theory

Increasing numbers of college students believe that the most important outcome of college is economic gain [1]. Many engineering educators reinforce this belief by arguing that the undergraduate engineering curriculum provides credentialing that leads to higher paying jobs and develops enhanced cognitive skills that prepare the student to perform that job [2]. While this viewpoint has merit, it ignores more significant benefits of the higher education process.

Behavioral scientists classify performance into cognitive and affective domains [2]. 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. Affective issues include 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 such as “engages in lifelong learning,” “understands the impact that engineering has on society,” and “communicates effectively” in their assessment of engineering programs [3]. Besterfield-Sacre *et al.* observe that students’ attitudes about engineering and their abilities change throughout their education and influence motivation, self-confidence, perception of engineering, performance, and retention [4]. The same group also found that attitudes toward engineering directly related to retention during the freshman year [5]. Seymour and Hewitt [6] examined students who left engineering programs and found that they were not academically different than their peers who continued in the program and that their retention was better correlated with attitude than with academics. For many students, college challenges their level of motivation and the 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 states “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” [7]. 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 [8], it clearly refers to two distinct, but related issues [9]:

- 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 control how he or she will approach a problem. Engineering professors tend to perceive barriers to student learning as lack of intelligence or motivation from students, when in reality, the student may lack awareness of the causes of the barriers he or she is facing.

Barriers to student learning also arise in connection with what has become a basic component of engineering education: working in teams. Experts agree on the importance of involving undergraduates in teamwork [10-12]. Seat and Lord [13] 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.* [14] 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.

### Specific Methodology

Weinstein and Meyer [15] describe the importance of students' understanding their own learning preferences, abilities, and cognitive styles, and discuss 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 will use the Learning Combination Inventory (LCI), a survey instrument developed by Johnston and Dainton to profile an individual's learning patterns [16]. 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 utilized 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 utilize 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 [16].

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 [17, 18]. 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 [19].

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 9 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 [19]. Studies conducted to verify the reliability and validity of the LCI are described in the *LCI Users Manual* [16].

The LCI has been used in the engineering program at Rowan University to enhance the

performance of student teams [20]. 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.

One issue noted during this study was that there was relatively less diversity among the profiles of engineering students compared to other students, which hindered the creation of balanced teams. Though not universal, there is a strong tendency for engineering students to lead with the technical pattern. We have also observed among our Rowan engineering students a tendency to exhibit relatively low scores—that is, in the “avoid” or low “use as needed” range—in precision and confluence, and relatively high scores—“use first” or high “use as needed” range—in sequence.

Our hypothesis is 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 [21]. 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 [22, 23].

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 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 keep information in their heads and do not readily volunteer it to others, they tend to write minimally, not seeing a need for a great deal of detail to be committed to paper.

We address this situation 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 faculty gain the knowledge and experience needed to integrate writing into their classes

- 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 [24]

We utilize the perspective available from the LCI to target the specific barriers to student learning we have identified.

### Process

All chemical engineering students have completed the Learning Combination Inventory (LCI) prior to beginning the Junior/Senior Clinic. The results of these surveys are used, to the extent possible, to form teams with compatible strategies that maximize the likelihood of success. The students also meet with Dr. Dahm, Dr. Newell and Dr. Hollar during the first week of clinic to discuss their LCIs and those of their team members. These discussions will include strengths and weaknesses of each preference, possible sources of conflict, consideration of how different people process information and approach problems, and ways to bridge differences in learning preferences. Because of the likelihood that team profiles are not balanced, students are counseled on the barriers presented by strong preferences for the technical learning pattern, so that team members will begin to fill the gaps created by lack of diversity.

Two activities that further this effort are bi-weekly status reports and focus groups. 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. During the pilot program, each member of each clinic team is required 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 [25] and the University of Texas at Austin [26] in which students write reflective pieces summarizing key concepts, discuss concerns, and (at UT Austin) create an analogy for the presented material. However, unlike these journals, the questions posed in the proposed status reports have 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 they have made suitable progress, but what issues are creating problems. Standardizing the status report across the department makes it a more valid assessment instrument, as well as a useful aid to the supervisor for project management. Dr. Harvey will work with Dr. Dahm, Dr. Hollar and both Drs. Newell to design assignment statements (including motivation) and rubrics for the evaluation of these status reports. The goal is to help students avoid hierarchical judgments and focus instead on what made their teams effective or ineffective.

Another proposed activity is formation of student focus groups. Dr. Dahm, Dr. Hollar and Dr. Newell meet periodically with a focus group composed of student representatives from various clinic teams. Feedback from these groups will be used to improve the clarity and thoroughness of the reports and evaluate the impact they have on motivation and performance. To insure that responses are candid, students working under one faculty's supervision will be placed in the other's focus group.

There can be little doubt that writing within the engineering curriculum has intrinsic benefits of its own. Kranzber [27] 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 [28] now require the development of communication skills for engineering students. As a result, many engineering programs incorporate writing-to-learn in their curricula [29, 30]. The ability to formulate a coherent written report requires that the student think clearly about the technical engineering problem [31-34]. 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. Although not a specific goal of this project, an overall increase in student use of writing as a tool for engineering work is expected. This will be partially a result of increased practice. Further, we believe that once students are aware of how their predominant technical learning pattern proscribes their use of writing, they will be more likely to consciously decide to use writing more than they naturally would. Both factors are expected to yield more detailed documentation and communication, and hence higher quality student work. As a more explicit goal, we expect that combining awareness of their own learning styles and those of their teammates with a continual written dialogue focused on identifying barriers to success and identifying priorities will result in increased student success measured in terms of both individual and team performance.

### Preliminary Results

The status reports were piloted during the Fall semester of 2002. One immediate observation was that the faculty needed greater explanation of the role of these reports. Some faculty attempted to use them in place of technical reports and found them (not surprisingly) insufficient. Additionally, the purpose of the reports was not explained sufficiently to the students, who initially viewed the reports as busy work of limited value. A more uniform means of implementing the reports and increasing their value to the students was developed for the Spring 2003 semester, but results are not complete at this writing.

By the time LCI data were available for this years' cohort, clinic teams were formed and functioning. The authors decided that for the LCI to be useful, it must be shared with newly formed teams, before they develop intractable opinions of each other. All chemical engineering sophomores have taken the LCI and its incorporation will begin in Fall 2003.

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