

DEVELOPING METACOGNITIVE ENGINEERING TEAMS

JAMES NEWELL, KEVIN DAHM, ROBERTA HARVEY,* AND HEIDI NEWELL
Rowan University • Glassboro, NJ 08028

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 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 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 completely ignored 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, metacognitive learners must understand their strengths and weaknesses in learning and control how they will approach a problem. Engineering professors tend to perceive barriers to student learning as lack of intelligence or motivation, when in reality, students may simply lack awareness of the causes of the barriers they are 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.^[9-11] Seat and Lord^[12] observed that while industry seldom complains about the technical skills of engineering graduates, industrial employers and

Jim Newell is a Professor of Chemical Engineering at Rowan University. He currently serves as Secretary/Treasurer of the Chemical Engineering Division of ASEE and has won both the Ray Fahien award from ASEE for contributions to engineering education and a Dow Outstanding New Faculty Award. His research interests include high-performance polymers, rubric development and forming metacognitive engineering teams.

Kevin Dahm is an Associate Professor of Chemical Engineering at Rowan University. He received his BS from Worcester Polytechnic Institute in 1992 and his PhD from Massachusetts Institute of Technology in 1998. His current primary teaching interests are assessment of student learning and integrating process simulation throughout the chemical engineering curriculum.

Roberta Harvey is an Assistant Professor in the Composition and Rhetoric Department at Rowan University. She holds a PhD from the University of Wisconsin–Milwaukee and team-teaches the innovative multidisciplinary design and composition Sophomore Clinic course at Rowan. She is certified to administer LCI surveys.

Heidi Newell is currently the assessment coordinator for the College of Engineering at Rowan University. She previously served as the assessment consultant for the ChE department at the University of North Dakota. She holds a PhD in Educational Leadership from the University of North Dakota, a MS in Industrial and Organizational Psychology from Clemson, and a BA in Sociology from Bloomsburg University.

* College of Communications, Rowan University

educators are often concerned with performance skills (*i.e.*, interpersonal, communication, and teaming). Lewis, *et al.*,^[13] 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.

Weinstein and Meyer^[14] 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 Combination Inventory (LCI), a survey instrument developed by Johnston and Dainton to profile an individual's learning patterns.^[15] 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 his/her 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:^[15]

- 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

Student awareness and understanding of their learning skills, performance, preferences, and barriers is referred to as metacognition. . . . In essence, metacognitive learners must understand their strengths and weaknesses in learning and control how they will approach a problem.

- performance.
- 3) Learners receive the most effective instruction when their teachers have an appreciation for their diverse learning characteristics.

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.^[16-17] The developers of the LCI explain the difference between their approach and that of learning styles in this way:^[18]

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.

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.^[18] Studies conducted to verify the reliability and validity of the LCI are described in the *LCI Users Manual*.^[15] Professor Newell participated in a three-hour workshop on learning preferences and consulted regularly with personnel for Let Me Learn. Professor Harvey has subsequently begun a 10-week intensive course

involving 28 hours of instruction on all aspects of the LCI.

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 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 technical learners are distinguished by a love of challenges, which serves the Junior/Senior Clinic student well, they are 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 to 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.

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:^[23]

- *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*

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

METHODOLOGY

All chemical engineering students had completed the Learning Combination Inventory (LCI) prior to beginning the Junior/Senior Clinic. They met with Dr. Dahm and Dr. James Newell during the first weeks of clinic to discuss their LCIs and those of their team members. These discussions included 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. 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 sequences, 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 team as up-tight 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.

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 immediately begin hands-on work and are less likely to read directions or perform a comprehensive literature review first. While having technical learners is beneficial 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.

Two activities that further enhanced this effort were bi-weekly status reports and team charters. Most faculty members, in supervising a clinic project, require some sort of periodic progress report or update. Historically, however, there

has been little coordination between faculty concerning the scope and format of these status reports. In the Fall 2003, every faculty member in the chemical engineering department 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. Unlike these journals, however, the questions posed in the proposed status reports have the student focus on barriers to completing the project, team dynamic issues, and prioritization. They represented an effort to have the student evaluate not only whether they have made suitable progress, but also what issues are creating problems. Standardizing the status report across the department made it a more valid assessment instrument, as well as a useful aid to the supervisor for project management. An additional goal is to help students avoid hierarchical judgments and focus instead on what made their teams effective or ineffective.

Also during the first week of the semester, each team 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. Note that only chemical engineering faculty members participated in this preliminary test, so chemical engineering students who were working on projects supervised by faculty members in other engineering disciplines were not required to form a team charter or participate in any of the other activities described in this section.

There can be little doubt that writing within the engineer-

ing 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

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.

Only one engineering student showed an avoidance for the technical pattern. When this was discussed with her teammates, they immediately decided to send her to the library to start the initial literature review while the other members of the team went directly to the lab to figure out the equipment.

Although not a specific goal of this project, an overall increase in student use of writing as a tool for engineering work was observed. This was partially a result of increased practice. Students were surveyed about the effectiveness of the various aspects of the team charters, status reports, and LCI interpretations. The survey used a four-point Likert scale. Table 1 summarizes the key findings.

From these results, it is clear that the students felt the team charters helped them focus on teaming issues and that the LCI discussion helped them understand the differences in problem-solving approaches among their teammates. One

TABLE 1
Results of Metacognitive Student Survey

<i>Survey Question</i>	<i>Mean Response</i> <i>4=strongly agree</i> <i>1=strongly disagree</i>	<i>Percentage of</i> <i>respondents who agree</i> <i>or strongly agree</i>
The team charter helped my team define expectations.	3.4	85
The LCI discussions helped me understand differences in how my teammates approach problems.	3.4	80
The biweekly status reports helped our team identify priorities.	3.2	77
The biweekly status reports helped with team dynamics.	2.8	62

team specifically referred to the value of the team charter when one member stopped showing up and eventually left the major. Many teams actually developed formal grievance procedures for their teams, even though they were not asked to do so as part of the assignment.

The teams seemed to value the status reports as a mechanism to identify barriers, but were less convinced of its role in aiding team dynamics. Several students suggested that the biweekly status reports should be shared with their teammates instead of just being submitted to the faculty team leader. Although the reports were submitted individually, the consistency within groups of identifying barriers and priorities showed that the teams were communicating effectively.

In support of the student responses, the faculty observed that not a single clinic team supervised by a chemical engineering faculty member in the fall of 2003 experienced crippling team dynamic issues. While anecdotal, this observation is compelling. In a typical semester, there are several teams that struggle, and there is at least one team that fails to meet its semester goals for reasons directly attributable to team dynamics. In the fall of 2003, one chemical engineering senior who worked on a project supervised by a civil engineering faculty member (and consequently was not participating in the teaming exercises described here) was on a team in which communication between members was so poor the team failed to turn in a final report.

From these data, it appears that combining an 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 resulted in increased student success measured in terms of both individual and team performance.

REFERENCES

1. Austin, A.W., *What Matters in College: Four Critical Years Revisited*, Jossey-Bass Publishers, San Francisco, CA (1993)
2. Engineering Accreditation Commission, *Engineering Criteria 2000: Criteria for Accrediting Programs in the United States*, 2nd ed., Baltimore: Accreditation Board for Engineering and Technology, Inc. (1998)
3. Besterfield-Sacre, M., C.J. Atman, and L.J. Shuman, "Engineering Student Attitudes Assessment," *J. Eng. Ed.*, **87**, 133 (1998)
4. Besterfield-Sacre, M., C.J. Atman, and L.J. Shuman, "Characteristics of Freshman Engineering Students: Models for Determining Attrition in Engineering," *J. of Eng. Ed.*, **86**, 139 (1997)
5. Seymour, E., and N. Hewitt, "Talking About Leaving: Factors Contributing to High Attrition Rates Among Science, Mathematics, and Engineering Undergraduate Majors," Bureau of Sociological Research, University of Colorado, Boulder, CO. A final report to the Alfred P. Sloan Foundation on an Ethnographic Inquiry at Seven Institutions (1994)
6. Study Group on the Conditions of Excellence in American Higher Education, *Involvement in Learning*, National Institute of Education, Washington, DC (1984)
7. Brown, A.L., J.D. Bransford, R.A. Ferrara, and J.C. Campione, "Learning, Remembering, and Understanding," in *Handbook of Child Psychology, Volume 3. Cognitive Development*, 4th ed., John Wiley and Sons, New York, NY (1984)
8. Angelo, T.A., and K.P. Cross, *Classroom Assessment Techniques: A Handbook for College Teachers*, 4th ed., Jossey-Bass, Inc., San Francisco, CA (1993)
9. Guzzo, R.A., and M.W. Dickson, "Teams in Organizations: Recent Research on Performance and Effectiveness," *Ann. Rev. of Psychology*, **47**, 307 (1996)
10. Katzenbach, J.R., and D.K. Smith, *The Wisdom of Teams: Creating the High Performance Organization*, Harvard Business School Press, Boston, MA (1993)
11. Byrd, J.S., and J.L. Hudgkins, "Teaming in the Design Laboratory," *J. Eng. Ed.*, **84**, 335 (1995)
12. Seat, E., and S.M. Lord, "Enabling Effective Engineering Teams: A Program for Teaching Interaction Skills," *J. of Eng. Ed.*, **88**, 385 (1999)
13. Lewis, P., D. Aldridge, and P. Swamidass, "Assessing Teaming Skills Acquisition on Undergraduate Project Teams," *J. of Eng. Ed.*, **87**, 149 (1998)
14. Weinstein, C., and R. Mayer, *The Teaching of Learning Strategies*, MacMillan, New York, NY (1986)
15. Johnston, C., and G. Dainton, "Learning Combination Inventory Users Manual," unpublished manuscript (1997)
16. Yokomoto, C.F., and R. Ware, "Applications of the Myers-Briggs Type Indicator in Engineering and Technology Education: Part II," presented at Proceedings of the ASEE Annual Conference & Exposition, Charlotte, NC (1999)
17. Felder, R.M., G.N. Felder, and E.J. Dietz, "The Effects of Personality Type on Engineering Student Performance and Attitudes," *J. of Eng. Ed.*, **91**, 3 (2002)
18. Johnston, C., "Let Me Learn" website, Center for Advancement of Learning at <www.letmelearn.org> [accessed November 18, 2002]
19. Pearl, K.M., and L.M. Head, "Using Your Brain to Build Teams that Work: A Study of the Freshman and Sophomore Engineering Clinics at Rowan University," presented at Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, Montreal, Quebec (2002)
20. Newell, J.A., A.J. Marchese, R.P. Ramachandran, B. Sukumaran, and R. Harvey, "Multidisciplinary Design and Communication: A Pedagogical Vision," *Int. J. of Eng. Ed.*, **15**, 379 (1999)
21. Schmalzel, J.L., A.J. Marchese, and R. Hesketh, "What's Brewing in the Engineering Clinic?," *Hewlett Packard Eng. Ed.*, **2**, 6 (1998)
22. Newell, J.A., S. Farrell, R. Hesketh, and C.S. Slater, "Introducing Emerging Technologies into the Curriculum Through a Multidisciplinary Research Experience," *Chem. Eng. Ed.*, **35**, 296 (2001)
23. Office of Instructional Development, "A Proposal to the Bush Foundation for a Faculty Development Program in Writing Across the Curriculum from the University of North Dakota," University of North Dakota (1993)
24. Hirt, D., "Student Journals: Are They Beneficial in Lecture Courses?," *Chem. Eng. Ed.*, **29**, 62 (1995)
25. Korgel, B.A., "Nurturing Faculty-Student Dialogue, Deep Learning and Creativity Through Journal Writing Exercises," *J. Eng. Ed.*, **91**, 143 (2002)
26. Kranzber, M., "Educating the Whole Engineer," *ASEE Prism*, **28**, 28 (1993)
27. Canadian Accreditation Board, "1993 Annual Report," Canadian Council of Professional Engineers (1993)
28. Ludlow, D.K., and K.H. Schulz, "Writing Across the Chemical Engineering Curriculum at the University of North Dakota," *J. of Eng. Ed.*, **83**, 161 (1994)
29. Newell, J.A., D.K. Ludlow, and S.P.K. Sternberg, "Progressive Development of Oral and Written Communication Skills Across an Integrated Laboratory Sequence," *Chem. Eng. Ed.*, **31**, 116 (1997)
30. Elbow, P., "Teaching Thinking by Teaching Writing," *Phi Delta Kappan*, **37** (1983)
31. Van Orden, N., "Is Writing an Effective Way to Learn Chemical Concepts?," *J. of Chem. Ed.*, **67**, 583 (1990)
32. Wankat, P.C., "Reflective Analysis of Student Learning in a Sophomore Engineering Course," *J. of Eng. Ed.*, **88**, 194 (1999) □