Direct Competency Testing – Is It For You?

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Abstract

A pedagogical tool, Direct Competency Testing, has been developed to measure the ability of engineering students to find correct solutions to simple problems in a small number of specific "competency" areas for each course. Competency is demonstrated by finding a completely correct solution to at least one test problem in the stated area. Students must demonstrate competency in at least three areas to pass the course and in all areas to receive a grade of "A" regardless of their performance on regular course exams. Direct Competency Testing not only serves as a measure of individual student ability in the classroom, it also provides a convenient means of documenting program outcomes for the coming EC2000 accreditation process. Finally, and perhaps most importantly, it helps to prepare students for the practice of engineering where completely correct solutions are the only acceptable solutions.

Introduction

Have you ever asked yourself if it is possible for a student to earn an engineering degree without having produced a single completely correct answer on any engineering exam? Have you ever struggled over whether a student with borderline performance on traditional engineering exams, consisting exclusively of problems graded with partial credit, has acquired sufficient knowledge and skill to merit a passing grade and subsequently a degree from your program? Are you searching for innovative methods and tools for providing the program documentation demanded by EC2000 accreditation requirements[1]? We believe that most of our colleagues have considered some, if not all, of these questions at some time in their teaching careers. Our motivation in writing this paper is to share with those colleagues a pedagogical tool that can help serve as a partial answer to all of these questions – Direct Competency Testing, (DCT).

The experience reported herein evolved from a chance discussion between the two authors a few years ago that focused on the first question posed above: "Do some of our students graduate without ever producing a single completely correct answer to an exam problem?" Because traditional examinations are the major element in the grading system for most engineering courses, we concluded that this certainly could, and probably did, occur. We agreed that such an occurrence was certainly undesirable.

If a simple mathematical error is made during an exam, we generally attribute it to "time pressure" and, provided that the solution methodology is sound, give the student a passing score for that problem. While pedagogically sound, this same type of performance in a professional engineering setting is completely unacceptable. There is no question that in engineering practice the analysis must be completely correct so that sound and safe decisions can be made. It is not overly dramatic to say that human lives are often at stake. So, the question becomes: "How can we best prepare our students for professional practice?" DCT provides a valuable tool in pursuing that objective. Just as the student will discover in professional practice, DCT puts a premium on the correct answer. The student's performance is not judged on a sliding scale. It is either completely correct and, therefore, acceptable or it is not.

What is DCT?

As the theory and practice of the EC2000 Criteria[1] promulgated by the Engineering Accreditation Commission (EAC) of The Accreditation Board for Engineering and Technology American Board (ABET) propagates throughout the engineering education community, all engineering educators are becoming more familiar with the terms such as program mission, objectives, outcomes, competencies, and their interrelationships[2]. Depending on your point of view, competencies are either at the top or bottom of the structure. A competency is simply the ability to perform a specific task. Although in an engineering context this is often manifested as the ability to solve a particular kind of problem, it more broadly includes the ability to articulate a particular piece of information or to apply acquired knowledge or skill to accomplish a specified task. The crucial feature of all of these interpretations is that a competency has a very specific target as opposed to the more general statements embodied by educational outcomes and program objectives. For example, a program objective might be to produce graduates prepared for entry level professional practice. A corresponding educational outcome might be graduates who can apply fundamental principles to solve engineering problems. Finally, an associated competency might be the ability to determine the magnitude and line-of-action of the hydrostatic force on an inclined surface. The competency is specific and, therefore, the easiest of the three to measure. One useful metaphor relating the aforementioned terms is that of a building. If the program mission defines the type of building to be constructed, then the program objectives define its shape, the educational outcomes are the walls that produce that shape, and the competencies are the building blocks from which the walls, and thence the building, are constructed.

Direct Competency Testing, (DCT), is the activity of assigning a specific task and then determining whether or not the student has acquired the ability to perform that task correctly. Although this paper is focused on testing an individual competency with a pencil and paper activity, DCT can be performed in many different ways for many different kinds of competencies. A laboratory competency might require that a student perform a standard fundamental task, such as titration in a chemistry lab, under the supervision of an examiner. If the task is performed completely correctly, as measured by defined standards, then a record has been established that the student has acquired the requisite knowledge and skill to perform that specific task. From another perspective, it is conceivable that it may be desirable to construct an instrument that tests more than one competency at a time. From yet another perspective, can DCT be used to document more abstract outcomes such as "an ability to function on multi-disciplinary teams", (Criterion 3.d of Basic Level Accreditation Criteria specified by EC2000)? If an exercise can be constructed that meaningfully evaluates student ability in the area using a simple pass/fail criteria, then the answer is "yes." How to construct such an exercise may be daunting task. In fact, even if such an exercise can be crafted, it may not be the best way to document that a student has acquired a particular capability. DCT is just one tool in the toolbox.

How Have We Implemented DCT?

At the conclusion of our initial discussion of competency testing, the authors agreed that assessing our students' ability to obtain completely correct solutions to simple problems requiring a basic understanding of fundamental principles of engineering was highly desirable and we further agreed to experiment with such testing in our individual classrooms. This experiment has been ongoing for more than four years and, although the process differs slightly from semester to semester, the approaches seem to have converged to a fairly stable delivery system. The following paragraphs describe a few of our most recent experiences with DCT, not because we have been particularly smart or insightful, but rather to help explain the DCT process by example. In verbal discussions with our colleagues, we have found that one example is worth more than a thousand words.

Our primary test-beds for DCT have been our introductory undergraduate courses in dynamics, thermodynamics, and fluid mechanics. After several iterations, the following core competencies have been identified as the most meaningful indicators that our students have acquired the minimum knowledge and skill to receive a passing grade in the dynamics, thermodynamics, and fluid mechanics courses, respectively.

Dynamics: The ability to...
1) solve a simple problem involving particle kinematics in a rectangular coordinate system
2) apply Newton's Second Law to determine the motion of a body subjected to a given set of forces
3) apply the principle of conservation of energy to solve a simple dynamics problem
4) apply the principle of impulse and momentum to solve a simple dynamics problem
5) solve a simple problem involving planar kinematics of a rigid body

Thermodynamics: The ability to....
1) apply the First Law of Thermodynamics to a simple problem involving a closed system
2) apply the First Law of Thermodynamics to a simple problem involving an open system
3) solve a simple problem where knowledge of the properties of a pure compressible substance is required
4) solve a simple problem using the Second Law of Thermodynamics

Fluid Mechanics: The ability to …..
1) determine the magnitude and line-of-action of the hydrostatic force on an inclined plane
2) apply the principle of conservation of mass to a filling or emptying finite-size control volume
3) apply the principle of conservation of energy to flow along a streamline
4) apply the momentum-force principle to a stationary finite-size control volume
5) apply dimensionless parameters to organise information or specify model testing conditions
6) determine the pressure change due to flow through a pipe including local losses.

Clearly, each competency addresses one of the fundamental engineering concepts associated with a first course in dynamics, thermodynamics, or fluid mechanics and, while prescribing a fairly specific capability, leaves room for a wide range of problems to serve as a competency test.

The logistics of administering four to six competency tests during a 15-week semester is not trivial and is directly related to how they are integrated into the course grading scheme. One possible approach is to assign such a large portion of the course credit to the competencies that a student could not possibly pass the course without getting the competency questions correct. One problem with this approach is the interaction between exams designed to assess ability level and those designed to document minimum acceptable threshold abilities. Consequently, we chose instead to integrate the competency testing in precisely the same spirit with which they first arose: they are go/no-go tests. To receive an “A” for the course, a student must pass a competency exam in every topic area. If there is one topic for which a student cannot pass a competency exam, the highest course grade possible is a “B”, no matter how high scores may be on the other evaluative components of the course. If the student cannot pass a competency test in two of the topics, the highest grade possible for the course is a “C”. Failure to pass the competency test for three or more topics will result in a failing grade for the course regardless of the scores achieved on the other evaluative components of the course.

With so much importance attached to the competency testing, it seemed unreasonable to provide the students with only one opportunity to pass each competency. In the fluid mechanics course three opportunities are provided to pass a competency test for each topic. Each test requires only 10 minutes of class time to solve a problem designed to take no more than 5 minutes. These times can be short because the problems are relatively simple. The purpose of the test is to demonstrate a minimum competency.

Less class time can be devoted to this activity if the competency test problems appear as part of a traditional exam. When this is the case, the identified problem is graded on the basis of partial credit for the purpose of exam score, but the solution must be completely correct to satisfy the student’s competency requirement in that topic area.

A hybrid approach was used in the dynamics and thermodynamics courses. It employed the three 10-minute tests described above for each competency area, and also included each competency as a problem on at least one traditional full-period exam. The latter problems were considerably more difficult to work completely correctly, but provided the students one last opportunity for demonstrating a given competency.

Below are typical problems for the 10-minute exams in the three courses:
Dynamics: An automobile weighing 3220 pounds is moving at a speed of 60 mph when the brakes are applied, causing all four wheels to skid. Assume the coefficient of friction between the tires and the pavement is 0.80. Using the Principle of Impulse and Momentum, determine the time required for the automobile to stop.
Thermodynamics: A three-pound mixture of water and steam is contained in a rigid tank at 70 ^{o}F and has a quality of 10%. The mixture is heated to 150 ^{o}F. Sketch the process on a p-v diagram showing the saturation dome, and determine the final quality of the mixture.
Fluid Mechanics: A liquid chemical (S=1.2) is drained from a holding tank at a rate of 0.6 ft^3/s at the same time it is being pumped into the tank at a speed of 15 ft/s through a 5 in. dia. pipe. If the tank has an internal volume of 2,000 ft^3, how long will it take to fill the tank from half-full to completely full?

How Do Students Perceive DCT?

When first introduced to students as one component of course requirements, there appears to be a nearly unanimous groan: yet another new obstacle to success. Apparently, no amount of discussion can prepare the students for their first encounter with a competency test. Anxiety is understandably high as there is no room for error: I have to get this one right! What they seem to refuse to accept is that the competency problem was designed to document a minimum threshold ability and is, therefore, considerably simpler than a typical exam problem. It is always interesting to watch as students gain experience with DCT. Their attitude toward DCT usually moves from adversarial to neutral and not infrequently to a positive view of this type of testing. Once the initial apprehension has passed, most students recognise the competency test as a challenge but not as insurmountable obstacle. Some perceive it as a “tune-up” when the competency precedes a traditional exam. Some view the competency question embedded within a traditional exam as “the easy problem” on that exam. Perhaps most rewarding from an instructor’s point of view, several B and C students have mentioned after the course was over that, although they wished their performance on the traditional exams had been better, passing all of the competency exams gave them confidence that they had acquired a level of knowledge and skill in the subject area that would allow them to successfully function in the entry level of professional practice. Also, from an instructor’s point of view, it is interesting to note that, after 12 offerings of courses that included competency testing, not a single course grade has been lowered due to failure to pass a sufficient number of competency tests. This is entirely in line with experience related to incorporating graded homework as one component of the course grade: students with high homework scores typically show high performance levels on traditional exams. Likewise, students who score well on traditional exams also do well on the competency tests. It is interesting to note that nearly all students seem to try to pass all of the competency exams, even when it is clear that they have already passed a sufficient number of them to be awarded the grade they have earned from the other evaluative components of the course. Perhaps the competency test becomes a personal challenge or a habit. In either case, specific focus provided by DTC seems to have had a positive effect on the learning process.

How can DCT help meet EC2000 requirements?

One overly-simplified view of the change from previous ABET criteria to EC2000 is a shift in focus from “*What has the program presented to all students enrolled in the program?*” to “*What has been learned by every student that successfully completes the program?*” Criterion 3 for basic level accreditation under EC2000 begins with "Engineering programs must demonstrate that their graduates have …" and completes the sentence with specification of eleven program outcomes. Of the eleven, seven start the description of the outcome with the phrase, "an ability to …". In the past, program coverage was documented in part by published syllabi and by examples of student work such as exams, homework assignments, and projects, conducted primarily during the year preceding the accreditation visit. While such instruments can still be useful for documenting the program, unless the samples of student work have received perfect grades, they show a level of performance and not necessarily the ability to execute a particular task. This is where the fundamental difference between a traditional classroom exam and a competency test is again crucial. The traditional exam seeks to assess level of student learning, and its primary function is differentiation between students to determine appropriate course grade. A good exam produces a distribution of performance. In contrast, the competency test sets a minimum threshold of ability: a student either can or can't perform the task. This is the relevant issue for accreditation. Has the student acquired the requisite knowledge or skill? DCT can provide clear evidence that every student successfully completing a course has acquired a specified ability. Careful curricular planning can produce a set of competencies that, when taken in the aggregate, provide proof of a demonstrated educational outcome for every student. Returning to the metaphor of a building, DCT can produce the essential building blocks to demonstrate that program objectives are being achieved.

Another fundamental shift embodied by EC2000 is a new focus on the "process" of education. It is no longer adequate to document the educational experience provided by a program. To successfully pass an EC2000 review, the program must demonstrate that processes are in place to pursue continuous program improvement. This includes collection of data on student performance, evaluation of that data by faculty and other stakeholders in the program, and use of that evaluation to modify the program in pursuit of improving the educational experience. DCT can play a very useful role in the evaluation process. Because each competency is based on a precisely defined capability, it is relatively easy for all process stakeholders to use them as an evaluation tool. The faculty get near real-time feedback on student acquisition of requisite knowledge and skill and can therefore adjust instruction to bolster student comprehension if students cannot demonstrate competency in a particular topic. Industrial partners can evaluate the utility of existing competencies in preparing students for industrial practice and can propose revised or new competencies that they feel better meet the needs of industry. Students are also stakeholders in the educational process, and even they can use DCT as an evaluation tool. If student responses on a course evaluation indicate that all published competencies for that course have been covered, both students and instructors are assured that they have been properly prepared for further study. A negative response to such an inquiry immediately alerts the department chair and instructors for follow-on courses that there is a problem that requires immediate attention. As they near graduation from a program that extensively employs DCT, students have an inventory of specific capabilities that can be used by both student and prospective employer to determine their suitability for available positions. After a period of professional practice, alumni can provide unusually specific feedback to the program by identifying the competencies they have found most valuable, those which they feel have not been meaningful to them in professional practice, and they can identify competencies they believe would have better prepared them for professional practice. Therefore, DCT can be very useful for defining the curricular content of a program, for providing meaningful and specific evaluation of the program by all stakeholders, and ultimately for directing efforts at improving the program.

What Have We Learned and What's Next?

Direct Competency Testing, DCT, can be an effective pedagogical tool that provides important feedback to student and instructor on progress toward educational objectives. In addition to promptly identifying deficiencies, DCT can help students gain confidence in newly acquired capabilities. It can be implemented without placing an undue burden on the instructor or the students. For accreditation purposes, DCT can provide incontrovertible evidence that all students have acquired a minimum proficiency in a target topic. As a curriculum design tool, it can be used to ensure that every student develops the requisite knowledge and skill foundation without excessive duplication of effort within the program. DCT can be a tool that is easily used by all stakeholders in implementation of the data collection – evaluation – program revision process required for accreditation by ABET under EC2000. Although it is clearly not a comprehensive answer to all curricular issues, it can be one of the most useful tools in the toolbox.

DCT will never reach a state of perfection. There will always be a search for more efficient and effective methods for administering the competency tests, for integrating them into the course grading system, and for making them more meaningful for all process stakeholders. The authors believe that the experiences presented herein constitute a good beginning, but only a beginning, on the integration of DCT into our program. We hope that with continued experimentation we can make improvements in all aspects of how DCT is implemented in our program and we look forward to reading of other educators' experiences with this valuable tool.

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