Design Learning and the Assessment of Instruction

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Abstract

The accreditation of engineering design components of the curriculum is based upon a characterization of design as "... creative, iterative, and often open-ended ..."¹. The Universal Student Rating of Instruction (USRI) is based upon a composite of expectations including those involving: organization, detail in course outline, responses to questions, opportunities for assistance, evaluation methods, and perception of instruction. In this paper we examine the competing nature of these two characterizations.

Even the most casual perusal of the questions posed by the USRI reveals that the premise underlying this instrument is one that clearly (albeit implicitly) points to a number of expectations. The nature of the subject matter, the nature of the learning process, the learning environment, the role of the student, that of the instructor, and that of the relationships between all of these are all assumed to benefit from adherence to a particular pre-ordained form. Specifically, the curriculum is perceived to consist of a body of facts, the learning process involves a transfer of these facts from instructor to student, the role of the student is passive, and responsibility for learning is the sole preserve of the instructor. The authors hold that this most sterile and simplistic set of expectations is fundamentally at odds with what should be happening in a design course.

In this paper we juxtapose the nature of design and design learning with the teaching algorithm underlying the USRI.

1. Introduction

Implications that might be drawn from just the title of this paper are:

1. That design learning is important; hence
2. That the quality of design learning is important.

These implications are assumed to be acceptable at

face value by an audience of design instructors. For further evidence of this, one need look no further than the accreditation criteria of the Canadian Engineering Accreditation Board¹ or, indeed, the creation of the Canadian Design Engineering Network. The paper title also implies:

3. That there exists a causal connection between the quality of (design) instruction and design learning outcomes.

When operating within the context of an institution of learning it is quite natural and extremely tempting to assume that learning and instruction are *uniquely* linked in this fashion; in fact one need not look very far to realize that this model (i.e. consisting of an instructor feeding knowledge/information to the learner) does not represent a unique learning mode at all. It follows from this that the fourth implication drawn here –

4. That the quality of instruction is the prime controllable factor influencing the student's design capability -

should be questioned. The authors posit that drawing these latter implications betrays at best a limited – and at worst a fundamentally flawed – perception of the process of learning to design.

It has been observed that mastery of engineering design in traditional disciplines (i.e. civil, mechanical engineering) typically requires decades of experience. By implication, designers must become lifelong learners wherein the traditional instructor/learner relationship has but transient value. The authors further propose that engineering design learning should begin in a way that establishes effective learning patterns that will serve the designer throughout his or her career.

There is, however, a fly in the ointment. Expectations dictated by the educational institution – specifically comprising teaching evaluation instruments combined with promotion criteria – are currently rooted in the assumption that the only legitimate mode of learning casts students and instructors in specific roles; unfortunately, the roles

defined are clearly inconsistent with the type of learning that will best serve designers and creative problem-solvers. Consequently, satisfactory (let alone optimal) outcomes are unlikely to be sustainable.

In order to present this case, the authors begin by listing what are viewed to be some important goals for undergraduate engineering design learning. This is followed by a brief review of candidate learning modes that have been observed to either enable and/or support or alternately to inhibit or discourage aspects of the desired learning. The 'fit' of instruction assessment currently used at the University of Calgary *vis-à-vis* these models of learning is then examined. Finally, some results of alternate assessment approaches are presented.

2. Goals of engineering design learning

It is no more reasonable to expect that a general four-year undergraduate engineering programme would prepare graduating students to lead the design of a complex engineering system than it would be appropriate for newly-qualified private pilot to take the controls of a commercial airliner. However, the graduating student should clearly be capable of a) making an effective contribution to a large engineering design project; and b) independently completing a modestly-scaled project. Defining the specific objectives can be approached in different ways but it is convenient in this instance to describe a top-down description of learning targets that derive from the institution and the profession.

In 1997 the University of Calgary adopted a Strategic Learning Initiative (SLI)² that identified seven curriculum features (such as an 'experiential learning component ...') to be present in all undergraduate degrees, a graduating student profile incorporating seven types of capability (e.g. 'Establish and realize goals, working alone and with others'), and eight specific core competencies including 'Critical and creative thinking', 'Interpretive and assessment skills'. These are presented in full in the Appendix to this paper.

The SLI set targets that explicitly defined the scope and objectives of undergraduate curricula. It was decided by the Department of Mechanical & Manufacturing Engineering that the most effective way to achieve the desired outcomes was to expand the capstone design courses from a single semester course having limited scope to two semesters wherein the learning was to embrace most of the additional competencies and curriculum features. At the same time, plans were begun to shift the common core introductory design and communication (including graphics) courses in directions more consistent with

the SLI with some of the main goals including:

1. That basic competencies related to professional practice be acquired
2. That the nature of engineering (as distinct from science) be learned
3. That students begin to learn independently (less reliance upon 'road maps')
4. That integration of programme content would take place
5. That creativity be encouraged

By undertaking to offer accredited degrees, faculties of engineering require curriculum as specified by the CEAB Accreditation Criteria (*op cit*). By long tradition, the mathematical and scientific components of undergraduate programmes tend to be relatively well-defined. This is not the case with respect to design content. Perhaps coincidentally, the accreditation criteria pertaining to the design component shifted at the same time to include "... a significant design experience ... which preferably gives students an exposure to concepts of team work and project management."

It was against this background that the authors developed a number of specific learning goals for the capstone design courses in the department. These are enumerated as follows. In particular, students were expected to:

1. take responsibility for their learning
2. learn to deal effectively with uncertainty
3. learn to view the rest of their programme in terms of design tools
4. develop effective team skills
5. effectively interact with a variety of stakeholders
6. learn to effectively manage design resources while addressing conflicting requirements, and ultimately
7. learn to selectively apply appropriate tools to generate workable and defensible solutions to open-ended problems

These are intended to capture the intent of the learning objectives of both the university and of the CEAB.

3. Learning modes

Taylor³ describes three techniques of learning. The first is based upon recitation, classroom exercises and quizzes; the second involves learning by discussion (the 'preceptorial system'

introduced at Princeton by Woodrow Wilson in 1905), and finally learning by independent study.

In spite of the clear need to graduate students who are capable of learning by independent study, learning in the traditional undergraduate learning environment has come to be dominated by some combination of lectures, tutorials, and laboratories (with textbooks commonly incorporating both questions and answers). This particular mode of teaching is clearly suited to conveyance of an established, structured body of knowledge geared to formulaic solution processes. It is focussed upon solving 'sanitized' problems having precise, unique, and 'correct' answers. It also pre-supposes fixed roles and expectations of both instructor (authority figure and leader, active dispenser of knowledge, judge) and student (passive receiver of knowledge, follower, judged). While the student is expected to show up, pay attention, and hand in assignments on time, the instructor clearly bears the responsibility to organize, present, and explain the course content as well as either directly or indirectly judging student responses (typically against a pre-established template that constitutes the 'correct' answer).

Using this mode it is clearly possible to efficiently and effectively teach particular types of curriculum to large numbers of students. If engineering design were a subject that fit this mould it could be a useful approach. But while some specific design tools can be taught and learned within this framework, the high-value capabilities required for design (self-awareness, judgement, breadth of knowledge, communication, initiative, leadership, creativity, ...) cannot. More specifically, greater creativity is directed by students to minimizing involvement than in generating novel solutions; an incompletely defined problem is viewed as an instructional deficiency; since the instructor is the sole arbiter of success, the only judgement required of the student is aimed at determining the instructor's priorities and methods; and there is no motivation to give serious consideration to diverse points of view. So in almost every important respect, design learning fails to conform to the recitation template. But since it is a good fit with the student-as-customer paradigm, it continues to be attractive in the 'education as business' environment.

In the preceptorial arrangement (learning by discussion), the roles of tutor and student clearly depart from the recitational approach. This will be recognizable as a type of learning that graduate students may typically experience in their relationship with their supervisor. The student is expected to 'bring something to the table' and thereby take on more and more of the responsibility. As the student's learning advances, he or she can

become better equipped to lead the way into unexplored territory. Since the relationship requires good communication, these abilities tend to improve with use. Similarly, developing critical faculties is possible within this environment. On the other hand, the single tutor will still tend to be viewed as the prime authority figure and only latterly will the student be viewed as solely responsible for their learning. And finally, this learning mode is clearly predicated upon a very small student/tutor ratio – a situation that rarely exists in the undergraduate school.

There are related learning modes that many will recognize:

The relationship between the apprentice and the master craftsman is one that is built upon a close one-to-one relationship. The task of the master is to assign tasks to the apprentice that will provide a continually growing basis for learning. This may require some direct teaching/demonstration by the master but will tend to rely more upon provision of feedback on student work. At the same time, the apprentice is typically positioned to observe the work of the master and to engage the master in dialogue.

The student of a sport will be taught a variety of specific skills through a combination of repetitive exercises and actual play – the role of tutor in this case being recognized as that of the coach who may from time to time demonstrate skills but primarily supports learning by stipulating the activity to be undertaken and then providing feedback on what the student is doing.

The student of music performance benefits from feedback from the teacher. Whether in a band, chamber group, or in a master class for soloists, the music teacher spends most of the time listening and providing feedback rather than demonstrating. In this way, as in sport, the student can develop technical and creative strengths that may far exceed those of the coach (as performer).

Pilot training combines classroom (recitational) learning of a number of basic subjects (regulations, aerodynamics, meteorology, navigation, etc.) with one-on-one development of specific skills. The flight instructor will describe, demonstrate, guide, critique the manoeuvres to be learned

by the student and will closely monitor the skill development process to watch for deviations from acceptable practices. Again, the instructor will do very little of the actual flying. Instead, the instructor creates situations specifically designed to test the ability of the student to exercise appropriate judgement, decision-making skill, and the ability to recognize and recover from challenging circumstances (e.g. recovery from unusual attitudes).

By creating these situations and knowing to what extent the student can be allowed to safely stray into dangerous territory, the instructor can create the environment within which the student learns the skills, judgement, and appropriate degree of confidence. Just as the voice coach can lead the student vocalist to tackle repertoire appropriate to his or her physical and artistic capabilities, the wrestling coach can set up contests that balance the abilities of the students, the flight instructor can design a training session to stretch the ability of the student to handle bad weather and equipment failures.

In all of these cases the learning tends to be student-centred and the role of the coach or instructor is to both design the learning environment and to provide feedback to the student. Potentially the learning remains strongly influenced by the instructor; it is common for the student to carry the 'brand' of their mentor through much of their career (which can be either advantageous or problematic depending upon the reputation of the mentor). Typically the tutor has very limited capacity to directly support large numbers of students since there must be a very substantial one to one interaction.

The third mode identified above is the independent study mode. What is the role of the instructor here - if any? Taylor (*op cit*) relates two stories to illustrate a spectrum of possibilities regarding independent study. In the first, a young student progresses from recitational learning to independent study under the guidance of a mentor and in so doing is transformed from an underperforming undergraduate into a mature scholar. In the second case a mature student earns a Ph.D. in minimal time through intense self-study. In both instances the role of the instructor is to provide the learning environment – in the first case a laboratory and a problem; in the second a curriculum. What clearly distinguishes this mode from apprenticeship is the requirement for the student to look beyond the instructor for feedback and to cultivate his or her own ability to generate and test ideas.

Independent study appears, then, to provide

a sound basis for lifelong learning. When viewing the desired learning outcomes listed earlier in this paper, a case can be made that of the three learning modes listed here, independent study is most likely to achieve the most valuable of the educational goals.

4. Assessment of instruction

It has been stated (by this year's distinguished CDEN lecturer amongst others) that design cannot be taught – only learned. If this is the case then clearly the instructor's role could be perceived to be irrelevant and no assessment of instruction would be meaningful. When one re-examines the role of the instructor in either the apprenticeship model or the independent study mode, however, it should be clear that the most important role of the instructor is to create and maintain an effective learning environment. The authors posit that the effectiveness of a design instructor should be assessed within this context.

At present, assessment of all undergraduate instruction at the University of Calgary is dominated by the Universal Student Rating of Instruction (USRI) - an instrument that asks students to rate the instructor (not the learning environment) based upon the following criteria:

1. Overall instruction
2. Enough detail in course outline
3. Course consistent with outline
4. Content well organized
5. Student questions well responded to
6. Communicated with enthusiasm
7. Opportunities for assistance
8. Students treated respectfully
9. Evaluation methods fair
10. Work graded in reasonable time
11. "I learned a lot in this course"
12. Support materials helpful

The assessment form also provides space for written comments.

While it is possible to criticize both this instrument and its application, we will simply examine the 'fit' of some of these criteria with the role of the design instructor as we have cast it above.

If the responsibility for learning is placed with the instructor, then criteria (1), (4), (6), and (12) represent perfectly reasonable expectations; if responsibility is to lie with the student, however, the results be contraindicative.

If the course is based upon a fixed curriculum comprising specific knowledge and information then (2), (3), (4), (6), (12) represent appropriate questions. If, however, the focus of the

course is to be on acquiring design and learning skills, honing critical faculties, and exercising self-direction, these criteria don't fit the objectives.

Criterion (5) seems a reasonable expectation provided the instructor is the most appropriate person providing feedback - as students assume to be the case in most other courses. However, since one of the important goals of design learning is that students take on the responsibility for deciding who is best placed to respond to a particular need (such as technical support, the client, the user, a particular domain expert, etc.) it will generally be appropriate that the student **not** look to the instructor for this type of information. Similarly, criterion (7) is stated in a way that clearly implies that it is the responsibility of the instructor to provide all feedback.

Criterion (8) (Evaluation methods fair) is problematic since students tend to equate 'fairness' with 'objectiveness' and the associated existence of some 'precise, correct' answer to the problem that they are attempting to address. Students have been observed to be ill-prepared to accept the adjudication of an experienced designer in association with a visible benchmarking process. The culture of 'part marks' for effort, for part of a method, for reaching some sort of poorly communicated answer is firmly at odds with the need for rigour, completeness, clarity, defensibility, and initiative.

Students have also become accustomed to discovering and learning specific knowledge, information, and tools. Consequently these expectations are at odds with the learning goals in a design course - skills, attitudes, judgement, responsibility, and so on. The degree to which this can be the case was demonstrated by feedback from one particular student in the 'Comments' section of the USRI. As usual, for every negative comment there was another student with positive perceptions. One (anonymous) response stood out, however, for its vitriol (not quoted here to protect all parties involved). In particular, the comments:

- A. represented a clear violation of engineering ethical standards
- B. were factually in error
- C. were based upon expectations that were completely antithetical to those elaborated in the course documentation, and
- D. were directed at individuals who were not the party responsible.

In other circumstances this commentary might well have been actionable both professionally and legally; it is a sad commentary on the distance between expectations of a student and the goals of a design course.

It should not be surprising, then, that the USRI scores for design courses tend to be significantly lower than those for conventional courses even when the students have performed very well in terms of learning outcomes and grades. It is unfortunate that this ill-fitting assessment instrument is applied to one of the most challenging learning situations in the university.

There are, however, alternate approaches to the assessment. McGourty⁴, for example, alludes to an 'Assessment Toolbox' comprising a variety of templates geared to assessing specific learning objectives. A brief list might embrace:

- assessment of design project outcomes
- assessment of skills acquired
- assessment of the learning environment

Project outcomes may or may not be indicative of actual learning. Some students might arrive with enhanced capabilities in a particular domain which might be reflected in superior design project outcomes in spite of the absence of mastery of the all of the required competencies (because not all competencies are necessarily required to complete a specific project, for example).

Skill acquisition can be assessed in different ways. One approach that has been implemented at the University of Calgary is to ask the student to self-assess their skills improvement. At the end of the winter semester, all students are asked to complete an independently developed, anonymous evaluation. The primary focus of this evaluation is student skill development, but areas of learning opportunities & resources, team selection, and course instruction are also assessed.

In assessing skills gained, students are asked to respond to the question, "Engineering 253 has helped me develop skills in the following areas" for eight skill categories:

1. Working collaboratively with others.
2. Using drawing to communicate about design.
3. Communicating about design through writing.
4. Communicating about design through oral presentations.
5. Using engineering skills to work on design problems.
6. Using engineering skills to assess design solutions.
7. Working innovatively with design problems.
8. Approaching learning tasks more independently.

Students are asked to response using one of five

categories, ranging from Strongly Disagree (1) to Strongly Agree (5). Each skill category addresses one of the principle competencies of the first-year design course.

To date, this evaluation has been administered each year the first-year design course has been offered, giving us three years of results. On average, 80% of the 585 students registered in the class have completed the assessment (compared to 30% for the USRI). In general the assessment has supported the instructors observations that students are improving their design and communication skills. For example, in each year, at least 70% of responding students have agreed or strongly agreed that their skills in drawing, collaboration and innovation have improved. These are three important skills for graduating engineers.

The learning environment can also be assessed using multiple approaches. A method employed at the University of Calgary involves having every student write a letter to the class that will follow; the objective of the letter is to provide advice regarding how the course can best be approached. While formal methods to assess this feedback have yet to be developed, these letters do provide some excellent insights into how the learning environment is perceived. Since the only requirement is that the letter be cast in 'professional' terms, there is a tendency for students to provide constructive advice which itself becomes part of the developing learning environment.

The types of comments provided by the students are varied but many common themes reappear. Some samples of the types of comments written by the students are shown below:

"Having now realized how helpful the design trinity can be, I hope to use it to our benefit more often. By familiarizing ourselves with the problem we can move to testing. Testing in turn leads to functionality. And functionality then brings you back to familiarization."

"During the term I learned the importance of collaboration to produce effective tests, designs and to complete and hand in work on time. With the help of others tests and designs can be worked and reworked in a shorter period of time and with more feedback. By participating in groups the stress associated with the assigned projects was eased with the sense of combined confidence and knowledge. ENGG 251 has proven the importance of collaboration and teamwork when solving problems."

"To be completely honest I have to tell you that this course often frustrates me beyond belief. I found myself to be spending a humungous amount of time working on projects and assignments for this class that at the time I felt were utterly useless compared to the work I also needed to do in my other courses. Looking back I have come to realize that this course was very good for me, even the fact that it infuriated me at times."

5. Conclusions

The authors have demonstrated ways that design learning can embrace learning goals espoused by both the institution and the profession. They have also demonstrated how a traditional, formulaic approach to the assessment of design instruction fails to assess either the effectiveness of the instructor in creating and maintaining a high quality learning environment or the actual progress made by students in achieving the stated learning goals. Finally, some alternative approaches to assessment of design learning are presented.

6. References

- [1] – "Accreditation Criteria and Procedures", Canadian Engineering Accreditation Board, Canadian Council of Professional Engineers, 2003.
- [2] – "University of Calgary Undergraduate Curriculum: A Framework and Process for Redesign", Undergraduate Curriculum Redesign Team, September, 1999.
- [3] Taylor, H., "Effective Teachers and Teaching: their natures and techniques. Training Engineering Scientists - the need for new techniques. J. ASEE Mar. 1961 [As reproduced in *"Higher Education in Engineering and Science"*, H. Estrin & R. Van Houten, editors. McGraw-Hill, 1963.
- [4] McGourty, J., "Four Strategies to Integrate Assessment in the Engineering Educational Environment", *Journal of Engineering Education*, ASEE, Vol. 88, No. 4, pp. 391-396.

7. Appendix

The Three Cornerstones of Curriculum Redesign at the University of Calgary

Graduating Student Profile (Curriculum Redesign Final Report, October 1996)

Graduates of the University of Calgary are intellectually Powerful. They can:

- Pose questions which approach the frontiers of knowledge.
- Solve the academic, professional, and ethical problems they face.
- Relate theory and practice.
- Establish and realize goals, working alone and with others.
- Communicate meaning in competent and effective ways.
- Engage meaningfully with those from other cultural and linguistic communities.
- Understand the world from a variety of perspectives.

Core Competencies (Adopted January, 1997)

are a set of skills and abilities to be integrated into all curricula at the University of Calgary. Students should be competent at:

- Critical and creative thinking
- Analysis of problems
- Effective oral and written communication
- Gathering and organizing information
- Logical calculation
- Abstract reasoning and its application
- Insight and intuition in generating knowledge
- Interpretive and assessment skills

Seven Curricular Redesign Features (Approved June 18, 1998)

1. A clearly identifiable field of study
2. A defined interdisciplinary component
3. An international component
4. An experiential learning component relevant to the program objectives
5. Integration of research
6. Provision for broad and extended faculty student interaction at the program level
7. An explicit program syllabus, which sets out in advance the knowledge and skills to be acquired in a program of study