Assessment For Improvement In The Classroom

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Introduction

Masaaki Imai, in his book *Kaizen*[1], pointed out that unless a company continually strives to improve the quality of their products, the products' quality will decline over time, even if the products start out as first in class. The same is true for educational courses; unless we continually work at improving the quality of a course, the course's quality (effectiveness) will decline over time. The Second Law of Thermodynamics applies as much to courses and products as it does to heat engines.

There are a number of different continuous improvement processes (e.g., Plan Do Check Act). In its simplest form, the continuous improvement process is a cycle made up of the following three steps:

1. define a course,
2. assess the course, and
3. modify the course returning to step 2.

The authors of this paper have developed, assessed, and modified four major courses during the last five years (Introduction to Engineering Design, Intermediate Design Methods, Understanding Engineering Systems : Computer Modeling and Conservation Principles, Thermodynamics). This paper presents our current thinking about the continuous improvement process and provides some of the tools and techniques we are currently using. The paper will discuss, in order, the three steps of this process.

Step 1 - Defining A Course

We have found that the best way to define a course is to answer the four questions posed by Ralph Tyler[2] in 1949; specifically:

1. What educational purposes should the school seek to attain?
2. What educational experiences can be provided that are likely to attain these purposes?
3. How can these educational experiences be effectively organized?
4. How can we determine whether these purposes are being attained?

We have developed a compact way of organizing the answers to questions 1 and 2 (and perhaps 3), which we will present but first it is important to understand how we define the learning objectives, i.e., how we articulate the answers to question 1.

Learning Objectives - What Is Involved?

In developing the learning objectives associated with a course we rely on the following assumptions about learning:

1. There is a taxonomy associated with learning, i.e., there are different levels of learning to which someone can know and use information (knowledge).
2. The different levels of learning are observable or measurable.
3. The levels of learning are reasonably hierarchical.

The first and second assumptions reflect the observation that there are noticeable, measurable differences between a novice and an expert in how they use information. The third assumption is based on the observation that successful demonstrations of the higher levels of learning are generally not possible before successful demonstrations of mastery of the lower levels.

Given these assumptions about learning, defining learning objectives for a course involves defining not only the things to be learned (i.e., the competencies) but also the change in level of learning that is expected in the competency. We use a version of Bloom's[3] taxonomy to define the changes in level of learning.

The Course Articulation Matrix - A Compact Definition Of A Course

As mentioned earlier, the answers to the first two (and to some extent the third) of Tyler's questions can be compactly presented in what we call a **Course Articulation Matrix**, see Figure 1 for a portion of such a matrix. The first two columns are used to define the learning objectives (the answer to Tyler's first question) while the items in the first row after the second column define the course learning activities (the answer to Tyler's second question). Thus, for the Introduction to Engineering Design course, Figure 1 shows that two of the major learning objectives for the course are to learn:

1. the Engineering Design Process to the Application level of learning and
2. how to Work in Teams to the Comprehension level of learning.

Further, the figure indicates that some of the learning activities are taking quizzes, reading and summarizing, and dissecting and reassembling an artifact.

After the learning objectives and learning actives have been entered into the matrix, the matrix is completed by entering the level of learning associated with each (competency, activity) pair. Thus is Figure 1, the quizzes represent a Knowledge level of learning activity for the various design process sub-objectives while the project work serves as a Comprehension and Application level of learning activity. When you look at Figure 1 you notice that many of the possible (competency, activity) pairs are blank, which makes sense, since any individual learning activity rarely, if ever, impacts on all of the course learning objectives.

Tyler's third question (how to organize the learning activities) is answered, at least partially, by studying the articulation matrix. Since it is assumed that the levels of learning are hierarchical, it follows that the activities associated with the lower levels should come before the activities associated with the higher levels. Thus in Figure 1, it follows that the reading, lectures and quizzes take place before the active learning activities which would take place before the design, build, test project. This sequencing of activities would move the student from Knowledge to Application for the Engineering Design Process.

Learning Objectives	Level of Learning	Course Activities	In Class Activities	take quizzes/exams **before** class	active learning exercises	construct mathematical models	orally report to peers and class	peer assess design notebooks	work on design projects	watch manufacturing/other videos	listen to brief lectures	Out of Class Activities	read and summarize textbooks	construct model based on geomety	Projects	dissect and reassemble artifact	develop an assembly plan (process)	design, build, and test a device	demonstrate design
1. Engineering Design Process	A																		
1.1 formulating the problem	A			K	C		C		C		K		K			C	C	A	A
1.2 solving a problem	A			K	C		C		C		K		K			C	C	A	A
1.3 implementing a solution	A			K	C		C		C		K		K			C	C	A	A
1.4 documenting the process	A			K	C		C		C		K		K			C	C	A	A
1.5 using engineering/physical principles	K					K													
1.6 using quality principles	A			K	C		C		C		K		K			C	C	A	A
2 Working in Teams	C																		
2.1 team dynamics	C			K	C				C		K		K			C			
2.2 team communication	C			K	C				C		K		K			C			
Level of Learning Legend	**K** Knowledge				**C** Comprehension						**A** Application								

Figure 1 - A Piece of the Course Articulation Matrix for Introduction to Engineering Design

Step 2 - Assessing The Course

The second step in the continuous course improvement process is monitoring or assessing how well the course is operating. We feel there are four major aspects of a course that need to be assessed:

1. the student's work,
2. the mastery of the course's learning objectives,
3. the learning environment, and
4. the student's level of learning coming into the course.

Each of these areas will be briefly discussed with at least one assessment technique presented and discussed.

Using Checklists To Assess Student Work

There are work products (homework, written/oral reports, exam papers, design notebooks, etc.) associated with each of the learning activities detailed in the Course Articulation Matrix. For each learning activity shown in the matrix, it is assumed that when a student successfully completes the activity, the student will have demonstrated mastery of the competencies

Yes	No	Expected Requirements
		1. Is the team name (i.e., number) shown?
		2. Is there a brief description of the product?
		3. Are the target markets (primary and secondary) defined?
		4. Are there assumptions that constrain the development effort?
		5. Are the stakeholders define?
		6. Is it word processed and no more than one page long?
		7. Is the proposed product acceptable to TeamUSA (if not why)

Figure 2 - Comprehension Level Of Learning Checklist For A Mission Statement

associated with the learning activity at the levels of learning shown in the matrix. For this assumption to be true, it is important to clearly define in advance of assigning the activity what characteristics, attributes, content will be expected in the work product if the work product is to prove mastery of the competency.

We have found that checklists are a very useful method of articulating what we expect to find in the work product when the work has been done satisfactorily[4]. In its simplest form, a checklist is a collection of Yes/No questions (see Figure 2). In this simplest form, if a student's work gets all *Yes's* then the student has demonstrated mastery of the competencies at the levels of learning shown in the articulation matrix for the activity. A single *No* would mean the student had not yet successfully demonstrated mastery and further work would be required. We have found the use of this simple checklist to be quite useful in introductory courses.

The activity associated with the checklist shown in Figure 2 is to write a Mission Statement for a new product that a team wants to develop. The activity offers the team a chance to demonstrate that it can write an acceptable Mission Statement when asked to do so (hence a Comprehension level of learning activity). The checklist shows there are five content items (and one formatting item, number 6) that must be addressed if the Mission Statement is acceptable. The Mission Statement may contain other information but the faculty who defined the course have indicated, by the checklist, what they feel constitute the minimum acceptable Mission Statement.

When checklists are used for assessment, there tend to be three possible outcomes. The work either meets expectations, exceeds expectations, or falls below expectations and needs improvement. Work that receives all Yes's is assessed as at least meeting expectations but could be assessed as exceeding expectations based on the quality of the presentation, the amount of relevant work, the quality of the discussion, etc. Work that receives a single No is assessed as needs improvement.

What "grade" you associate with these three outcomes depends upon your expectations but generally exceeding expectations is an A, meeting expectations is a B or C, while needing improvement would be a C or D. Failing grades are generally reserved for work not submitted. We generally set our expectations, as defined by the checklists, high enough that meeting expectations is B level work.

Understanding Engineering Thermodynamics :
Computer Modeling and Conservation Principles

Name: Smith, Oveyon Guamon

Before Class l

After Class

Last Update 3 / 19 / 98 2 : 42 PM

				Affective Objectives			*Cognitive*		
			Number	**Receiving**	**Responding**	**Valuing**	**Knowledge**	**Understanding / Comprehension**	**Application**
Learning Outcome	*Competency Category*	*Competencies*	**130**						
	1 Problem Solving Heuristic	Problem Definition	**1.1 - 1**						
		Generating Alternatives	**1.1 - 2**						
		Deciding the Course of Action	**1.1 - 3**						
		Implementing the Solution	**1.1 - 4**						
		Evaluation	**1.1 - 5**						
		Parameters (Shared)	**1.2 - 6**						
		Coordinate System (Motion Easy?)	**1.2 - 2**						
		Data (Nature)	**1.2 - 3**						

Figure 3 - A piece of a Competency Matrix for a first course in Thermodynamics

One last note on checklists. The question always comes up as to whether the students should have the checklists before they submit their work. We have found that it is generally a good idea to make the checklists available at the time the work is assigned. The checklists do not indicate what it takes to exceed expectations only what it takes to meet expectations. For students to generate quality work products they need to know their customer's (i.e., the Faculty's) expectations and the checklists offer a good way to define what is expected.

Using A Competency Matrix To Assess Learning Outcomes

The second issue that needs to be assessed is whether the learning outcomes, defined in the Articulation Matrix, have been accomplished. While it is true that if a student got a meets or better for all the activities, the student would have demonstrated mastery of all the learning objectives, there are some drawbacks to relying solely on checklists to monitor the entire course. First, students rarely get meets or better on all the activities which is all right if there are multiple activities that can be used to establish mastery. A second drawback is that checklists focus only on portions of the course learning objectives; checklists do not give a good measure of how the entire process is working. These shortcomings can be overcome by using a Competency Matrix.

Tyler[2] (page 50) may have actually developed the first Competency Matrix. The current use of Competency Matrices in assessment has been extensively reported elsewhere[5], thus only a very brief overview will be presented here. A Competency Matrix is similar to the Articulation Matrix, in that it details the competencies to be mastered in the first few columns. A typical matrix shows a three level deep organization to the competencies (see Figure 3), the top level being Learning Outcome, the next level down being Competency Category, and the lowest level being the Competencies themselves. The first Learning Outcome for the Thermodynamics course does not appear in Figure 3 but is Modeling Thermal Systems. This Outcome is divided into ten Competency Categories (1 shown and one partially started). The first Competency Category has five Competencies associated with it.

Unlike the Articulation Matrix the columns of the Competency Matrix are the various cognitive and affective levels of learning (degrees of internalization). In Figure 3, three affective columns and three cognitive columns are shown. The cross hatched regions highlight the areas in the matrix where the learning is expected to take place. Figure 3 shows that for the Thermodynamics course, students are expected to achieve Responding and Comprehension for the five Competencies associated with the *Problem Solving Heuristic* Competency Category.

The matrix starts out empty but, as work is completed and accepted as meeting expectations, the matrix's cross hatched boxes are filled in with some type of mark. For example, if a student submitted work that demonstrated Comprehension level of learning for *generating alternatives* (competency 1.1-2), the student would put in the box where *generating alternatives* intersects with Comprehension either the date, a checkmark or the page location in her portfolio where the submitted and assessed work could be found.

Filling in the matrix gives the student a picture of how they are progressing towards mastering all the learning objectives. By studying the matrix a student can determine what competencies need to be worked on (an extra assignment perhaps). The student can also determine what sort of work might exceed expectations; generally any appropriate work at a higher than expected level of learning would qualify as work that exceeds expectations.

Using The Course Activity Impact Matrix To Assess The Learning Environment

The third aspect of the course that needs to be assessed is the learning environment itself. It is important to know how well the environment has helped (or hindered) the learning of the course material. There are many different ways to monitor the environment. Some of these methods are used regularly throughout the course (e.g., plus / deltas and Likert scale process checks, electronic forums and chat rooms, etc.) and some methods are used only after the course has finished (e.g., a Course Activity Impact Matrix). Since the periodic assessment methods are fairly well known we will only discuss the creation and use of the Course Activity Impact Matrix.

A Course Activity Impact Matrix (CAIM) allows students to assess the impact that the course learning activities had in helping them achieve the learning objectives of the course. A CAIM is very similar to a transposed House of Quality diagram. The matrix has the desired learning objectives as columns (the needs in the House of Quality) and the learning activities (Tasks) as the rows (the *hows* in the House of Quality). Part of the CAIM used in the Intermediate Design Methods course is shown in Figure 4. Notice the learning objectives are fairly high level, corresponding more to the learning objectives in the Competency Matrix than to the individual competencies. Four learning objectives are shown in Figure 4, there are three others not shown (Organize/Present, Report and Critical Thinking). The learning objectives are rather cryptically described in the matrix; the complete CAIM package includes a fuller definition of the objectives (e.g., Communication means "improved communication skills and attitudes").

As with the learning objectives, the learning activities (designates as Tasks in the matrix) are only present at a relatively high level of abstraction. Not all activities are included in the matrix. Figure 4 shows eleven tasks and, as with the learning objectives, the complete package better defines what is meant by each task. For example, the task *U & E Textbook* is described as "I read and studied the Product Design and Development (U & E) Textbook".

Completing the matrix is a three step process. First the students must establish the relative importance of the learning objectives. A pairwise comparison matrix is supplied with the complete CAIM package to help facilitate the generation of these relative learning objective weights. The relative weights shown in Figure 4, show that the student who filled out the matrix felt that learning how to solve problems (weight of 0.16) and improved communication skills and

	Objectives	COMMUNICATION	DESIGN	WORK WITH OTHERS	PROBLEM SOLVING	
	Weights	0.149	0.064	0.039	0.160	
Tasks		**1**	**2**	**3**	**4**	Dot Prod
Design Project	**1**	9	9	9	3	4.99
Memos	**2**	9	1	3	1	2.98
U&E Textbook	**3**	1	9	3	9	3.34
Prepare Reports	**4**	3	1	9	1	3.49
R&P Textbook	**5**	9	0	1	3	3.63
Assessed Design Notebooks	**6**	0	3	3	0	0.31
Quizzes	**7**	0	0	0	0	0.00
Presentation Sandwich	**8**	0	0	0	0	0.82
Assessed Oral & Written Reports	**9**	1	0	3	0	1.79
Lectures	**10**	3	0	0	0	2.21
In-Class Activites	**11**	0	1	1	1	1.79
						25.35
Success in achieving the criterion	high / low	4.0	2.0	3.0	3.0	

Figure 4 - A part of a Course Activity Impact Matrix (CAIM) for Intermediate Design Methods

attitudes (weight of .149) were more important learning objectives than improving design skills (weight of 0.064).

Once the weights are known, the students then assess the impact of each task on each of the learning objectives. A scale of 9 (high impact), 3 (moderate impact), and 1 (some impact) is used. If there is no impact of a Task on a Objective, that cell is left blank (or a zero entered). In Figure 4 the student has indicated that the *Design Project,* the *Memos*, and *R & P Textbook* (the communication textbook) had a high impact on her mastering the desired Communication skills and attitudes. The student also felt that four of the tasks had no impact at all on the Communication learning objective.

The last step in the process involves qualitatively assessing how much was learned, how successful the course was at achieving the learning objectives. A Likert scale from 4 (very successful) to 1 (low success) is used. In Figure 4 the student felt the *Communication* learning objective had been very successfully completed while the *Design* learning objective had not been achieved very well.

The last column show in Figure 4 is an important column; it is the dot product of the values in the matrix and the weights for the learning objectives. The dot product allows you to rank the impact of a task on all the objectives. The dot products in Figure 4 range from a high of 4.99 for the *Design Project* task to a low of zero for the *Quizzes* task. A dot product of nine would mean the task had a high impact on every learning objective, a value of zero would mean the task had no impact on any learning objective. The dot product results shown in Figure 4 indicate that the student felt the *Design Project* had a big influence on mastering the course learning objectives while the student felt that *Quizzes* did nothing for any of the course learning objectives.

Using Readiness Assessment Tests

The last aspect of the course that needs to be assessed is really the first thing you do in a course, determine if the students have the expected skills and attitudes. Both the Course Articulation Matrix and the Course Competency Matrix present the learning objectives in terms of a change in the level of learning which implies the existence of an assumed entry level of learning for the students entering the course. The matrices shown in Figures 1 and 3 are for an entry level course where the student is assumed to have no real knowledge of the subject matter coming into the course. But this is clearly not the case for follow on courses. In such courses the assumed initial level of learning might be Comprehension, Application, or even Analysis.

Historically we have relied on a student's "passing" a prerequisite course as evidence that the student has achieved the desired entry level of learning for our courses. The problem with this historical approach is two fold. First, many courses do not have clearly defined learning objectives (i.e., no Articulation Matrix) which makes it difficult to know what the students have learned in the course. Second, even when learning objectives are present, there is often a gap in levels of learning between what was accomplished in the earlier course and what is assumed as input to your course.

Since much of our recent effort has been focused on the Introductory engineering course, we have not spent much time developing tools to assess the readiness of the students. We do use a simple survey to collect computer skills data so that during team formation we make sure every team has at least one member who is comfortable using computers and that no team has more than one person who has never (very infrequently) used a computer.

Step 3 - Modifying The Course

The last step in the continuous improvement process involves the analysis of the assessment material and the adjusting of the course based on the assessment data. There are two places to make changes. First, the learning activities of a course can be modified. Second, and less frequently done, the learning objectives of the course can be changed.

Modifying The Learning Activities

The first step is to organize the assessment data so it can be used. There is not enough time to consider all the data that is collected and it is important to be able to zero in on the important aspects. If Likert scale process checks have been used a Pareto Chart (an organized bar chart) is quite useful in organizing the information. If the CAIM has been used, the results can be summarized by averaging the results of the individual students. Such a summary is shown in Figure 5.

After the data has been organized it needs to be analyzed. A quick look at Figure 5 shows that the students felt the *Design Project* task helped considerably more in achieving the courses learning objectives than any other task. The second most useful task was a tie between the *Preparing Reports* and *Assessed Oral and Written Reports* tasks. At the opposite end, *Quizzes* were felt to have had only some marginal impact on mastering the learning objectives. The results suggest that if you have only a limited amount of time available to spend on improving

	Criteria	COMMUNICATION	DESIGN	WORK WITH OTHERS	PROBLEM SOLVING	***S***	
	Weights	0.170	0.157	0.150	0.207		
Tasks		**1**	**2**	**3**	**4**	Dot Prod	%
Design Project	**1**	5.40	6.60	7.80	3.80	5.30	22
Memos	**2**	5.00	0.20	1.20	0.60	1.88	8
U&E Textbook	**3**	1.00	4.20	0.60	2.80	2.16	9
Prepare Reports	**4**	3.40	0.60	3.40	0.80	2.77	12
R&P Textbook	**5**	3.40	0.40	0.80	1.20	1.67	7
Assessed Design Notebooks	**6**	1.20	3.40	3.40	1.00	1.87	8
Quizzes	**7**	0.40	0.60	0.40	0.60	0.50	2
Presentation Sandwich	**8**	3.60	0.20	0.60	0.80	2.06	9
Assessed Oral & Written Reports	**9**	3.80	1.00	2.60	1.00	2.64	11
Lectures	**10**	1.80	1.00	1.20	0.40	1.22	5
In-Class Activites	**11**	1.60	1.40	1.80	1.00	1.54	7
						23.62	
Success in achieving the criterion	high (4) low (1)	2.60	2.40	2.40	2.20		

Figure 5 - Summary of the results from the Course Activity Impact Matrices completed by students in Intermediate Design Methods Class, Fall 1997

the course, time spent on improving the Design Project has the best potential of improving the learning environment for many of the learning objectives. Further, if you look at the values in the column under *Problem Solving*, you see that the students did not feel any of the course activities had much impact on improving their problems solving skills and attitudes. Finally the summary of how well each learning objective was actually learned was fairly low, with Communication getting the highest score of 2.6.

Once the data has been analyzed, possible changes to the course can be considered. Based on the data contained in summary CAIM, the Spring 98 offering of the course had even more time invested in the *Design Project*. The low impact of the *Quizzes* is troubling. We expect this is due to the students dislike of taking quizzes before the material is used in class as much as to their sense that quizzes do not help them learn. The low rating does suggest we consider the possibility of a different way to assess knowledge level of learning (which is all we use quizzes for, a sort of readiness assessment test for the new material).

In the Introduction to Engineering Design course we have used the results for the CAIM to modify the way we used Academic Journals. The journal activity was initially required of all students. CAIM results from the first few semesters showed very low scores, even after repeated attempts to justify the journals to the students. After the third semester we modified the activity and made the journals optional but, if the journal was done to meet expectations, the journal could be used to reduce the number of questions missed on a quiz and still receive an Exceeds or Meets expectations for the quiz, i.e., we made the journals worthwhile to the students, rewarding them for the extra effort the journal requires.

Modifying The Learning Objectives

As indicated earlier, modifying a course's learning objectives is not something that is frequently done but it is justified in some instances. The most common instance involves a change in the expected level of learning delta because the incoming students have not actually achieved the assumed level of learning. In such instances the course must supply activities that will allow the students to move up to the needed level of learning. Such a move will generally require the removal of activities and it may no longer be possible to achieve as high a level of learning for some of the competencies. Careful work with the Course Articulation Matrix is required.

Summary

Continuous improvement is a necessity of life if you want to keep your courses from deteriorating. The continuous improvement process is a cycle of defining, assessing, re-defining and re-assessing. The definition of a course can be compactly displayed using a Course Articulation Matrix which shows the learning objectives (competencies to be learned and the level of learning they are to be learned to) as well as the learning activities used in the course. Assessing the course involves many different areas. Checklists can be used to assess individual pieces of work, the Competency Matrix can assess the overall course learning objectives, and the Course Activity Impact Matrix can be used to assess the quality of the various learning activities. Re-design the course requires the analysis of the assessment data.

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