Int. J. Engng Ed. Vol. 23, No. 2, pp. 325–337, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A Design Methodology for Choosing an Optimal Pedagogy: the Pedagogy Decision Matrix*

DAVID M. MALICKY, SUSAN M. LORD AND MING Z. HUANG
Department of Engineering, Loma Hall, University of San Diego, 5998 Alcala Park, San Diego, California 92110, USA. E-mail: dmalicky@sandiego.edu, slord@sandiego.edu, minghuang@sandiego.edu

Engineering educators may have a sincere desire to enhance student learning but be unsure how to choose from a wide array of pedagogies. The aims of this paper are to: (i) delineate situational factors that influence the risks, benefits and implementation strategies of pedagogical choices and (ii) present a systematic approach to guide educators in choosing an optimal pedagogy. Using engineering design analysis methods, this paper presents a pedagogical assessment tool that accounts for factors related to students, course, instructor and institution. This tool may be useful for designing a course, continuous improvement of curriculum and optimizing allocation of resources.

Keywords: cooperative learning; decision matrix; inquiry-based learning; pedagogy; problem-based learning; project-based learning; service learning; subject-based learning

INTRODUCTION

NUMEROUS STUDIES AND REPORTS have called for improvement in modern engineering education [1–4] and a wealth of literature exists on effective pedagogies. And, many engineering faculty members are sincerely interested in enhancing student learning. However, there is generally a large gap between these two. Efforts such as the NSF-funded 'Rigorous Research in Engineering Education (RREE): Creating a community of practice' [5] provide a useful approach to bridging the gap between education researchers and engineering educators for those engineering educators who are interested in making pedagogy a focus of their research. However, it is not practical or reasonable to expect all engineering educators to share this interest or to stay current with the education or engineering education literature.

Even if engineering educators have some understanding of various pedagogies such as active learning, cooperative learning and problem-based learning (PBL), they may not have in-depth knowledge nor know which approach is best for their own classes or students. Indeed, the literature shows a large multitude of pedagogies, each of which has promoters citing compelling evidence for its adoption. Further, attempting a new pedagogy requires unclear but substantial investments of time and resources; investments that might not pay off if the pedagogy is not well matched to the instructor's particular course and environment. Thus the decision to try a new pedagogy is characterized by both benefits and risks. Both of these may co-vary with many situation-specific factors such as the instructor's tenure status and students' prior expectations. One thesis of this paper is that both traditional and non-traditional pedagogies have advantages and disadvantages. To help the educator address these difficult decisions, this paper aims to: (i) delineate the major situational factors that influence the risks, benefits and implementation strategies of common pedagogies and (ii) present a systematic approach to guide the educator in choosing an appropriate pedagogy.

We provide a tool—the pedagogy decision matrix (PDM)—to help guide engineering educators in choosing an optimal pedagogy given their unique situation. The PDM is a decision analysis framework whereby several pedagogies are rated in terms of their suitability according to a variety of situational factors. This personalized tool provides a systematic approach that helps minimize the risk of failure and optimize allocation of resources. The tool is based on engineering design methods such as decision matrices and pairwise comparison charts and thus should be familiar and comfortable for engineering educators. The approach we take here is similar to that of selection design. In other words, we consider the problem of choosing an optimal pedagogy as an open-ended design task. By casting the ambiguous selection process as that of design, the feasibility of applying common design analysis techniques becomes apparent. By having a prescribed set of assessment factors, an optimal pedagogy may be arrived at in the same way as how existing analysis techniques can be applied to select a best design out of a number of potentially viable options.

* Accepted 6 December 2006.

OVERVIEW OF PEDAGOGIES

A brief overview of common pedagogies is given in this section to establish a common background. Only those thought to have the most relevance for engineering education are included here. More details about particular pedagogies are available in the references cited. This is based on work previously reported [6, 7].

Traditional pedagogies

- Subject-based learning: the organizing principle for subject-based learning is the subject itself. Most courses have been taught using this pedagogy so it is very familiar to instructors and students. It is also well supported in terms of resources since textbooks are almost universally subject based. This results in a coherent and logically organized presentation, but it may lack relevance and context from the student's point of view. Instruction should thus include additional material to enhance student motivation. Subject-based learning is amenable to achieving subject-based course objectives though it can be difficult to achieve professional objectives such as teamwork and communication that are required by ABET 2000.
- Cookbook laboratories: the traditional laboratory format, the organizing principle for a cookbook laboratory is set of clearly defined steps that closely guide the student through an experimental procedure. The student follows these steps, often without significant initiative or forethought and achieves a successful result. This results in a relatively smooth-running laboratory that is likely to reach a conclusion, but often does not engage students enough to result in substantial learning. Hands-on experiences are vital for a hands-on profession such as engineering. Cookbook laboratories are most appropriate for training on equipment and procedures but are not optimal for deep learning or retention of concepts.
- Group work: students work together on a project in groups typically assigned by the instructor. In addition to the constraints of limited resources, the motivation for the instructor to include groupwork is often to meet ABET criterion D, 'an ability to function on multi-disciplinary teams' and/or to emulate professional practice. Such groupwork is typically unstructured and lacks any explicit group processing guidance or procedures.

Active/engagement pedagogies

The engineering education literature demonstrates considerable attention to active pedagogies or 'pedagogies of engagement' [8]. This literature has been driven by the lack of success of traditional pedagogies in achieving student outcomes such as teamwork, communication and diversity to satisfy most engineering educators and employers. In this paper, active/engagement pedagogies are interpreted to mean pedagogies that encourage students to be active participants in shaping their learning inside and outside the classroom:

- Problem-based learning (PBL): the motivation and organizing principle for a problem-based course is a set of carefully selected open-ended problems. The instructor develops the problems so that they require the student to achieve the desired learning objectives in the pursuit of solving the problem. The presentation of the problem is the first step in the learning cycle and the pursuit of the problem solution directs all learning activities. Learning of new material is student centred and self-directed. A high level of student initiative is required for learning to take place. Problem-based learning is typically done in teams or groups with teachers as facilitators. PBL's theoretical basis is its relative similarity to the tasks that working engineers actually do. Problem-based learning does tend to improve deep learning, knowledge retention, open-ended problem solving skills, team skills and positive student attitudes [9–12]. However it is somewhat controversial; criticisms include: 1) 'PBL may not always lead to constructing the 'right' knowledge' (Perrenet [13], in Mills [14], p. 7); 2) PBL results in little or no improvement on exam scores [11, 15]; and 3) PBL may lead to lower teacher ratings [15]. Some implementations of PBL provide significant prepared guidance from the instructor [10] and this appears to improve student acceptance. For the curriculum as a whole, Brodeur [16] recommends a progressive implantation of PBL: 'early experiences are designed to be success experiences with greater levels of faculty direction and support. As students' confidence and initiative grow, they are introduced to more complex, unknown, real-world applications' (p. 7). PBL originated in the medical school at McMaster University and there is evidence for its benefits in these settings; evidence is less clear for engineering curricula [10–12,15,17].
- Project-based learning (PjBL): similar to PBL, the motivation and organizing principle for a project-based course is one or more open-ended projects. The abbreviation PBL is frequently used for both PBL and project-based learning. To avoid confusion, we propose PjBL for project-based learning. While there is considerable overlap between problem-based and project-based pedagogies, the latter tends to be: 1) closer to professional practice, 2) aimed towards the application rather than the acquisition of knowledge [14] and 3) accompanied by subject-based courses. Typical deliverables from PjBL include technical reports, presentations and physical artifacts. The distinction between PjBL and PBL is often not made in the literature, although it is helpful to distinguish them when trying to determine which pedagogy is

most appropriate for a given instructor and course. The most common implementation of PjBL in engineering is for capstone design courses.

- Inquiry-based learning: the organizing principle for inquiry-based learning is the scientific method; as such inquiry learning is often used in laboratories. Students observe a carefully selected phenomenon, form a hypothesis about that phenomenon, develop an experimental procedure to test their hypothesis, perform their experiment, evaluate their results and reflect on their learning. Learning is again centred on the student, interactive with peers and relatively self-directed. Teachers function as facilitators. Inquiry learning typically requires less student initiative than PBL in that the scientific method is made explicit and followed. Still, it provides excellent training in design of experiments and the scientific method. Pedagogies known as structured inquiry and guided inquiry are often used to bridge the gap between cookbook laboratories and fully open inquiry learning, for students who may not yet have sufficient scientific skills [17]. Structured/guided inquiry also carries fewer demands of equipment and instructor time, though more so than cookbook laboratories. There is considerable evidence that the inquiry pedagogies increase critical thinking skills and depth of understanding of concepts [17–20].
- Cooperative and collaborative learning: cooperative learning and collaborative learning both describe a learning environment where students work together towards a common learning goal. While the two terms are often used interchangeably, they are not identical. As described by Karl Smith et al. [8], cooperative learning is highly structured and includes positive interdependence (all members must work together to complete task) as well as individual and group accountability. In Smith, Johnson and Johnson's model, cooperative learning must include individual accountability, mutual interdependence, face-to-face interaction, appropriate practice of interpersonal skills and regular self-assessment of team functioning [11]. Felder [21] provides a summary and recommendations for adopting cooperative learning. Collaborative learning need not be as structured and may not include all of the features of cooperative learning, such as individual accountability. Many examples of these types of learning are found in the literature. The experiences could range from simple in-class exercises where students form temporary groups and work on problems to cooperative learning homework teams that are in place for an entire semester with alternating assigned roles and peer rating. In engineering, most implementations of PBL and PjBL utilize teams of students. Thus these pedagogies may overlap with either collaborative or cooperative learning depending on how the teams are structured, monitored and assessed [8, 11, 21]. When engineering educators use the terms cooperative or collaborative learning, they are usually distinguishing their efforts from traditional group-work in terms of some amount of attention to group formation, developing teamwork skills and assessment of group function.
- Service learning: as students become involved in significant learning outside the classroom, these activities may be described as service learning. In this pedagogy, community needs are matched with academic learning goals and a reflection component aids in the students' processing of their experiences and knowledge gained. The incorporation of service learning in engineering has been rapidly increasing and gaining acceptance with the most visible example being Purdue University's Engineering Projects in Community Service (EPICS) programme which began in 1995 and has now spread throughout the US [22] (http://epics.ecn.purdue.edu). Service learning has been shown to have many student benefits, particularly for the ABET criterion of social and global impact and especially if it is structured to encourage development of socially responsive knowledge [23]. This pedagogy often overlaps with PjBL and/or cooperative learning as it can be structured around a team project for a community customer such as a school or nonprofit organization. Such projects often encompass a wide range of experiences within engineering and thus service learning is often multidisciplinary. Examples include first-year design projects where students present results to middle school students, to a mini-project within a solar engineering course where students performed the thermal design of a house for Habitat for Humanity, to multi-year projects where students from first through senior year work together to develop toys for disabled children or to improve access to social services for at-risk children [24].

Mixed methods

A number of options exist for combining the pedagogies discussed in this paper. Perhaps the most common and most practical are to combine traditional subject-based learning with projects or cooperative learning. In such approaches, a course would be organized by subject using a traditional textbook. Thus the instructor has the benefit of a well-organized structure but can try to incorporate some of the enhanced student learning benefits of more active pedagogies. There are a large number of permutations possible, the following represent some of the more common mixed methods:

- Subject + project-assisted learning: this type of course includes at least one group project. For example, in a sophomore Statics class students could design and build a balsa bridge in the last few weeks or juniors in an electronics class could design and build a feedback amplifier at the end of the semester. Another example is to start off the class with a project, such as to design and construct a catapult in a junior design practice course and use the students' own artifacts to demonstrate principles of design and optimization [25].

- Subject + cooperative learning: in its simplest form, this could involve having students do informal cooperative learning activities in class such as think—pair—share. This could also involve incorporating cooperative learning homework teams which function throughout the entire semester or team projects where there is a focus on group process, teamwork and individual accountability [26].
- Subject + project-assisted + cooperative learning: the subject + project-assisted pedagogy usually utilizes teams of students for the projects. If a cooperative learning framework is applied to those teams, the benefits of both of these active active/engagement pedagogies may be realized.
- Problem-based + cooperative learning: most implementations of PBL also use teams of students. Applying the cooperative learning framework to PBL achieves further benefits.

One could also combine a number of these pedagogies. For example, problem-, project-, product-, process-, people-based learning (P^5BL) was successfully used in a multidisciplinary architecture/engineering/construction curriculum. [27]

PEDAGOGY DECISION MATRIX METHODOLOGY

Situation-specific factors

Smith et al. [8] pose this question:

> Are some types of engineering classes (freshman or senior, lectures or project-based or laboratories, theoretical or applied) more or less conducive to any of the pedagogies of engagement? (p. 96).

The literature indicates that the best choice of pedagogy depends on a number of situational factors related to students, instructor, course and institution. For example, if the course is a prerequisite for other courses, there is less latitude for failure when experimenting with a radically different pedagogy.

The factors described here represent a compilation of those found in the literature and posited by the authors. An instructor may examine these factors to evaluate the risks and benefits of a particular pedagogy for a course they intend to teach. The characteristics of these factors will not uniquely select nor automatically exclude a particular pedagogy for a particular course.

Students: student factors can be clustered under three areas: skills, willingness and class dynamics:

- Student capacity for self-direction:
  - Student maturity: is the class made up of first year students who are trying to decide if they want to major in engineering or seniors ready to go to industry? Are the students relatively mature independent thinkers? Do they have reasonably sound organizational and deductive processing skills so that they are able to develop a solution to the problem? If the answer is no, an approach such as full PBL might lead to unproductive levels of student frustration. These issues are particularly relevant to PBL, PjBL and open inquiry learning.
  - Prior experiences: have the students already practiced, for example, PBL? If so they will more easily adapt to a similar pedagogy?
- Student willingness to accept a non-traditional pedagogy:
  - Expectations: what are the students' expectations for the course and instructor? Do they expect a logical and orderly presentation of theory and practice that parallels the textbook, or are they flexible about course format? Do they expect the instructor to have carefully prepared stepwise material or will they accept the instructor as a guide on the side? Will they accept coverage of fewer topics in more depth with the understanding they may need to learn some topics on their own? These questions are most relevant for PBL, PjBL and open inquiry learning. Students that strongly resist a non-traditional pedagogy may be all the more in need of it to become independent thinkers. A sink-or-swim approach carries high risk of failure; gradual changes are recommended.
  - Prior experiences: what non-traditional pedagogies have they experienced before? If they have had good (or bad) experience with a non-traditional pedagogy before, they are likely to be open (or resistant) to it again. If they have only experienced traditional passive lectures, they might: 1) resist an approach that expects them to take a highly active role, if they already feel excessively taxed with work; or 2) welcome an active role, if they are bored or tired of being passive.
- Class dynamics and ethos:
  - Do the students already tend to work in groups? Do these groups work reasonably smoothly or is there an unusual number of conflicted relationships present? If the class tends to be conflicted or lacks social skills, cooperative learning may be all the more needed, but additional time would be required for group selection and class processing.
  - While most students are oriented towards personal achievement, to what extent do they value, for example, social and environmental issues? Service learning may be more indicated where socio-environmental concerns are lacking, but its implementation would likely require additional efforts for enthusiastic acceptance. It is important to make clear the relevance of service learning for achieving

the academic learning goals and the requirements for the course. If the service learning is perceived as an add-on, students may sincerely resist.

Instructor: the instructor factors—skills, risk-acceptability and time—provide a framework for instructors to self-assess fit with different pedagogies:

- Instructor skills:
  - Pedagogical skills: what prior training and/or experience does the instructor have with non-traditional pedagogies? Does the instructor pick up new approaches quickly or slowly?
  - People skills: what are the instructor's group process skills, so they can effectively work through group roadblocks and conflict? Does the instructor have a good reputation with students so they are more likely to trust the new approach? Can the instructor effectively influence students to work hard and try something new? Skills such as these can be improved with training and practice.
  - Subject-specific skills: has the instructor taught this course before? Is this course in the instructor's technical area? For example, does the instructor have sufficient knowledge of the subject matter and its application in order to form good problems for PBL?
- Instructor acceptability of risk:
  - Tenure status: is the instructor tenured, so that they can afford to both invest additional time and potentially absorb a lower teaching rating [15, 28]? Or, does the instructor need to improve ratings to achieve tenure and thus needs to try something new?
  - Personality: how comfortable is the instructor with risk, ambiguity and loss of control of class? As Felder [29] advises, 'it is better to take small steps and gradually to increase the level of commitment to the approach, never venturing too far beyond the zone of personal comfort and confidence' (p. 5).
  - Motivation: why did the instructor become an engineering educator? How much personal interest does the instructor have in enhancing student learning and/or adopting new pedagogies?
- Instructor time:
  - Is the instructor burdened with an especially heavy teaching, research, or service load? Cline [28] states: 'the biggest problem incurred in the switch to PBL was the added support PBL required of course instructors. Asking students to tackle so much had inherent problems' (p. 6). Time factors appear to be most important for PBL, open inquiry learning and service learning courses and potentially important for cooperative learning and PjBL.
  - Does the instructor already have prepared lecture materials for a subject-based course or do new materials need to be developed? If materials already exist, using a different pedagogy such as PBL or open inquiry learning will certainly require significant extra time. If an instructor is just beginning to develop new materials, it may be more efficient to start with a more active pedagogy.

    Is their time sufficiently flexible to dedicate additional time when needed to address problems?

Course: the type of course has many factors associated with it:

- Learning objectives: to what extent do the learning objectives focus on knowledge, analysis, critical thinking, deep learning, problem solving, communication, teamwork, design and/or hands-on skills? Each pedagogy tends to promote certain subsets of these skills while de-emphasizing others. For example, subject-based learning tends to achieve objectives such as knowledge acquisition but it may not achieve professional objectives such as teamwork and communication that are required by ABET 2000.
- Future implications: is the course a pre-requisite for more advanced courses that require full breadth of coverage in the foundation course? While PBL and PjBL pedagogies increase depth, they may be less efficient at providing breadth. However, while traditional pedagogies may cover material, they may not induce understanding sufficiently for use in advanced courses. A careful review of core learning objectives is recommended to address this factor.
- Pedagogical resources: are there pre-existing resources to guide implementation of a non-traditional pedagogy for a particular course, such as published implementations or experiences from colleagues at one's institution or outside? A number of such implementation may be found in resources such as the *Journal of Engineering Education*, *International Journal of Engineering Education*, *Journal of STEM Education, Proceedings of the ASEE Annual Conference* and *Proceedings of the Frontiers in Education Conferences*. Useful information on implementing PBL in particular may be found at the University of Delaware PBL Website (http://www.udel.edu/pbl) and in a special issue of the *International Journal of Engineering Education*, **19**(5), 2003.

Institution: the main institutional factors are divided into two categories described here:

- Tenure and promotion expectations: does the institution or department prioritise teaching, in which case use of non-traditional pedagogies would likely be expected, or research, in which case some pedagogies would be more difficult to implement due to time requirements? Is the campus climate one where innovation is encouraged or is maintaining status quo expected?

- Support resources: are there adequate staff, equipment and IT resources to support the requirements of a PBL, PjBL, or inquiry-based pedagogy? Is there a center for learning and/or teaching on campus to support innovative pedagogical efforts?

Pedagogy decision matrix (PDM)

How do these factors translate into a tool that an instructor could use to choose a particular pedagogy? This problem is similar to those commonly encountered in engineering design where a best option needs to be selected out of a number of feasible ones during the conceptual design phase. The so-called best option is understood not as being universal but local; i.e. one that fits best with a set of specific criteria. Given a set of assessment criteria, such a selection task can be effectively dealt with using common design analysis techniques such as pairwise comparison chart and decision matrix [30].

A decision matrix is a tabular instrument that is set up typically by listing all the feasible options (in cells across a row) versus the assessment criteria (in cells down a column). Evaluation is carried out by focusing on one criterion at a time as it is assessed against each of the feasible options across the row and assigned numerical scores. Such a format allows for systematic evaluation of all criteria against all possible options while permitting individual consideration of each criterion independently of others. For our PDM, the options across a row would be the pedagogies and the criteria down a column would be the situation-specific factors described in the section on traditional pedagogies.

Clearly some of these factors are interrelated and some may be more important than others in particular contexts. For example, at an institution where teaching is a priority, there may be significant overlap between the instructor and student factors while at a research-focused institution, there may be more overlap between instructor and institution factors. At a teaching-focused institution, the impact of teaching evaluations and thus student satisfaction might play a larger role while at a research-focused institution, utilizing time-efficient pedagogies may be a priority. These interconnections and relative importance are implemented in an analytical way in the PDM by using another useful instrument from engineering design: the pairwise comparison chart. This chart is used to set the weights for the criteria when their degrees of influences are considered to be different. In this case, the criteria are the situation-specific factors. They are listed in both cells across the row and down the column and are compared and scored one pair at a time. Consequently, the numerical weights for each criterion can be calculated systematically. Allowing for different weightings fits well with the goal of using the decision matrix as a framework for choosing among alternative pedagogies. Having interaction among the factors is not a problem since the goal of the PDM is not to identify the most important factor. Of course, an instructor could choose to assign weightings directly in a more holistic fashion rather than using the pairwise comparison chart. The analysis in this paper only assigns weights to the categories of the factors (students, instructor, course and institution), rather than individual factors. An instructor could also assign different weightings to individual factors if that would be useful.

The first step in completing the PDM is to determine the weightings for the four categories of factors using a pairwise comparison chart as shown in Table 1. The evaluator proceeds row by row beginning with students. Considering one pair at a time, a numerical score is entered for each comparison with six scores being entered in total (shown as U, V, W, X, Y and Z in Table 1). A value of 1 is assigned if the factor in that row is more important than the factor in the column, 0 if less important and ½ if equally important. Note that cells on the diagonal that correspond to self-comparisons are all assigned a value of zero so that they are not factored in the weighting calculations. Note also that one only needs to work through the cells above the diagonal of the matrix as each of the cells in the lower half of the diagonal must have a value equal to the 1's complement of its corresponding cell above the diagonal so as to maintain consistency. For example in Table 1, the evaluator would start with the Students row. The first comparison would be students versus instructor where the evaluator would assign a value of U. The value of 1—U would thus be set for the instructor versus students comparison in the box below the diagonal. If the student factor is considered to be more important than the institution, then U is assigned the value of 1. The next value to be entered would be in the students vs. course comparison where the example in Table 1 has a value of V. The evaluator would then enter the values shown as W, X, Y and Z. The sum of the values in each column would appear as the Score. The weight factor is then the score for a given factor divided by the sum of the scores. The weight factors are given in percentages totalling 100%. Electronic versions of this pairwise comparison chart and the PDM are available at the University of San Diego (USD) Website [http://home.sandiego.edu/~dmalicky].

Once the weights of the factors are set, the next step in the evaluation process is to compare the pedagogies using the PDM an example of which is shown in Table 2. Note that each factor group contains two or three specific factors discussed in the section on situation-specific factors. The evaluator considers one factor at a time and evaluates it for each of the pedagogy options across the row. Numerical scores are entered according to the following metric: 5 = definitely suited, 4 = well suited, 3 = neutral, 2 = not suited and 1 = definitely not suited. For each factor

Table 1. Sample factor weighting pairwise comparison chart

	Students	Instructor	Course	Institution	Score	Weighting factor (%)
Students	0	U	V	W	U + V + W	Score/sum
Instructor	1—U	0	X	Y	1—U + X + Y	Score/sum
Course	1—V	1—X	0	Z	1—V + 1–X + Z	Score/sum
Institution	1—W	1—Y	1—Z	0	1—W + 1—Y + 1—Z	Score/sum
Total					Sum of scores	

group, the total numerical value for the specific factors is summed to form a subtotal. That subtotal is then normalized to a percentage of the available points, i.e. 15 for students, instructor and course and 10 for institution. Each of these normalized percentages is multiplied by the appropriate weighting factor from the pairwise comparison chart to form a weighted total for the factor group. Finally the weighted totals for the four factor groups are added together to determine the overall score. Note that this is a percentage with a maximum value of 100%.

EXAMPLES OF USING THE PEDAGOGY DECISION MATRIX

This tool for pedagogy selection was applied by the authors to several courses at different levels in several engineering disciplines. A brief description of the rationale for how the scores were assigned is provided for each example. For the purposes of the scope of this paper, the focus was on primarily traditional lecture courses with the most well-known pedagogical options: traditional subject-based, subject plus PjBL, subject plus cooperative learning, PBL and PjBL. Of course one may use the PDM and tailor the list of pedagogies as well as the assessment factors to reflect individual preferences.

Pedagogy selection for circuits course

The Circuits course is a sophomore level course that is foundational for electrical engineering majors. It is a prerequisite for many courses in the upper division. In this pairwise comparison chart, the entries in the Students row demonstrate that this instructor considered the Students factor to be as important as the Instructor and the Course factors but more important than the institution factor. Thus, the factor-weighting matrix resulted in equal weightings for students, instructor and course factors. Institution factor was weighted lower.

Table 2. Pedagogy decision matrix for circuits course. The following metric is used to evaluate each factor against pedagogy options: 5 = definitely suited, 4 = well suited, 3 = neutral, 2 = not suited, 1 = definitely not suited. The %score is subtotal divided by maximum available points (15 for factor groups A, B, C; 10 for factor group D)

	Pedagogies				
	Subject-based learning	Subject + project	Subject + cooperative	Problem-based learning	Project-based learning
A: Students (a = 25%)					
A1 Self direction	5	4	5	2	2
A2 Willingness to accept	3	4	4	4	4
A3 Class dynamics	3	3	4	3	3
Subtotal	11	11	13	9	9
% score A	73	73	87	60	60
B: Instructor (b = 33%)					
B1 Skills	5	5	5	3	3
B2 Risk tolerance	3	5	5	4	4
B3 Time	5	4	5	2	3
Subtotal	13	14	15	9	10
% score B	87	93	100	60	67
C: Course (c = 33%)					
C1 Learning objectives	4	5	5	2	2
C2 Future implications	4	5	5	1	2
C3 Pedagogy resources	5	3	4	1	1
Subtotal	13	13	14	4	5
% score C	87	87	93	27	33
D: Institution (d = 8%)					
D1 Tenure expectation	3	3	3	3	3
D2 Support resources	5	4	5	3	3
Subtotal	8	7	8	6	6
% score D	80	70	80	60	60
TOTAL (aA + bB + cC + dD) %	83	84	93	49	53

Table 3. Weighting pairwise comparison chart for circuits course

	Students	Instructor	Course	Institution	Score	Weighting factor (%)	
Students	0	0.5	0.5	0.5	1.5	25	= a
Instructor	0.5	0	0.5	1	2	33.3	= b
Course	0.5	0.5	0	1	2	33.3	= c
Institution	0.5	0	0	0	0.5	8.3	= d
Total					6	100	

The weighting factors determined in Table 3 were then used along with the guidelines presented in the section on PDM to fill out the PDM shown in Table 2. For this example, subject + cooperative learning is indicated as the optimal overall.

Students: typical students are sophomores who would not be expected to have strong self-direction. As such, one would expect them to be most comfortable with traditional subject-based pedagogies and least comfortable with PBL and PjBL. They were rated as having a medium willingness to accept new pedagogies. Being so-called millennials [31], the current generation of students has a preference for pedagogies that incorporate teamwork. Thus they may prefer something other than subject based. The class dynamics are still in formation. They may not have all met each other. They have only had one year of courses in common including at least one team project. Cooperative learning might help them foster better teamwork skills so it received a slightly higher score.

Instructor: this instructor currently employs cooperative learning strategies and small projects. Thus she is comfortable with these approaches. She is very interested in innovative pedagogies. She is interested in but has no experience with PBL and limited experience with PjBL. She is willing to take risks to enhance student learning. She believes that some students might be bored with subject-based learning, which is an additional motivation to try other types. The most time would be required for PBL and PjBL, thus the reason for low scores.

Course: circuits has many technically focused objectives (such as learning particular circuit analysis techniques, analyzing first and second order electrical circuits) that fall in multiple areas. There are typically not many professional skills included in objectives although this instructor now includes the ability to communicate solutions. Thus subject + project and subject + cooperative learning allows students to develop these other skills. Since there are many different and important topics that are used in later courses, it is critical that all objectives be addressed. Thus PBL might not be the best choice since some topics may be covered well and others missed. This would also be true of PjBL to a lesser extent. Subject-based learning might not provide the depth of learning that one would hope for and would be lacking for the professional skills. There are many textbooks available to support subject-based learning. Cooperative learning resources are also plentiful and relatively easily adaptable between disciplines. Projects are harder to adapt from other courses or disciplines. This instructor could not easily locate pedagogical resources concerning PBL or PjBL for circuits.

Institution: this instructor has tenure so the impact of her pedagogical choices on her tenure decision is not a factor for her. Very little support is needed from the institution for subject-based or subject plus cooperative learning. What is needed is also readily available since subject-based learning is the primary pedagogy used in this department. More resources could be needed to various degrees for the other pedagogies that might even involve laboratory components. The campus climate is varied. If the results are good, innovation maybe rewarded. In general, innovation is encouraged rather than discouraged.

Comments: based on the results of using the decision matrix in Table 2, subject + cooperative learning appears to be the most desirable pedagogy with a score of 93%. Subject and subject + project learning are not quite as desirable, but approximately equal to each other at 83 and 84%. PBL and PjBL appear to be undesirable since these scores are much lower.

Pedagogy selection for statics course

Statics is taken by the USD Mechanical, Electrical and Industrial Engineering sophomores and is a prerequisite for many mechanical engineering courses. This evaluation was conducted by a different instructor. The following explains the rationale for selection analysis with the results of factor weighting matrix and PDM given in Tables 4 and 5, respectively. Overall, subject + PjBL is indicated as optimal for this example.

Students: students are sophomores with moderate levels of self-direction and an interest in hands-on group activities. As such, the subject + project and subject + cooperative learning are well suited for this group. Student boredom is a concern for subject-based learning. The class dynamics are somewhat uncertain but appear to be typical.

Instructor: the instructor has practiced cooperative and PjBL but has no experience with PBL. He is a junior faculty member in a new programme with higher than average service duties. He wants to enhance student learning and is willing to take some risks, but cannot risk additional, heavy time

Table 4. Factor weighting pairwise comparison chart for statics course

	Students	Instructor	Course	Institution	Score	Weighting factor (%)	
Students	0	0.5	0.5	0.5	1.5	25	= a
Instructor	0.5	0	0.5	0.5	1.5	25	= b
Course	0.5	0.5	0	1	2	33	= c
Institution	0.5	0.5	0	0	1	17	= d
Total					6	100	

commitments. Thus PBL and PjBL are disfavoured for this instructor.

Course: this is a foundational course with many objectives relevant to future courses. Learning objectives are hierarchical within the course with later topics building on earlier topics. Long-term retention of knowledge is a concern since the material is often thought to be dry; thus pure subject-based learning is not favoured. There are some existing PjBL resources for certain parts of this course. It is important to achieve all the objectives; as such the mixed-methods pedagogies are preferred since they have been shown to enhance learning without risking loss of coverage.

Institution: the institution prioritizes effective teaching and thus less effective methods like pure subject-based learning are not preferred. There is limited support for resource-intensive pedagogies, however, which does not favour PBL and PjBL.

Comments: based on the results in Table 5, both of the mixed methods pedagogies are favourable choices for this course, with scores between 80% and 84%

Pedagogy selection for senior design course

Students: typical students are seniors who are finishing their undergraduate degree and looking forward to industry or graduate school. Thus they would be expected to have strong self-direction. As such, one would expect them to be comfortable with a variety of pedagogies and be eager to accept more responsibility and expect to be given a project for their senior design class. The class dynamics are mostly settled after several years of these students working together in small classes. They all know each other and hopefully would work well together leading to higher scores for PBL and PjBL.

Instructor: this analysis considered all three authors who had similar experience with this course as the instructor. Previous experience with PjBL led to higher ratings for it while inexperience with PBL resulted in lower ratings. Teaching in a purely subject-based way would have a high likelihood of disaster in terms of achieving learning objectives and student satisfaction so that was rated low. The amount of time it would take to

Table 5. Pedagogy decision matrix for statics course

	Pedagogies				
	Subject-based learning	Subject + project	Subject + cooperative	Problem-based learning	Project-based learning
A: Students (a = 25%)					
A1 Self direction	3	4	4	2	2
A2 Willingess to accept	2	5	4	2	3
A3 Class dynamics	3	4	4	3	3
Subtotal	8	13	12	7	8
% score A	53	87	80	47	53
B: Instructor (b = 25%)					
B1 Skills	3	4	4	2	3
B2 Risk tolerance	2	3	4	2	2
B3 Time	5	3	3	1	1
Subtotal	10	10	11	5	6
% score B	67	67	73	33	40
C: Course (c = 33%)					
C1 Learning objectives	4	5	4	3	3
C2 Future implications	2	5	4	3	3
C3 Pedagogy resources	5	4	4	1	3
Subtotal	11	14	12	7	9
% score C	73	93	80	47	60
D: Institution (d = 17%)					
D1 Tenure expectation	2	5	4	4	4
D2 Support resources	5	4	5	2	2
Subtotal	7	9	9	6	6
% score D	70	90	90	60	60
TOTAL (aA + bB + cC + dD) %	66	84	80	46	53

prepare lectures for pedagogies that required lectures (subject or mixed) or modules for PBL contributed to lower ratings for these.

Course: senior design typically has many professional skills such as teamwork and communication included in the course objectives. The technical objectives are focused on applying their knowledge gained throughout their undergraduate career in completing a significant project. Thus subject and subject and cooperative are given the lowest rating and PjBL the highest. Future implications of this course include student marketability. Students who have had a strong project experience are believed to be more marketable and better able to describe their experiences in interviews thus favouring PjBL and PBL over the other pedagogies.

Institution: this analysis was done for the same institution as the previous examples. For this course, if subject-based pedagogy contributed to poor student learning and student evaluations, it would have adverse impact on tenure and promotion decisions thus it was rated very low. However, since virtually no resources would be needed from the institution for subject-based learning, its rating for support resources was high. Currently at the USD, there is no support for PBL in the senior design course so support resources received a low rating. While PjBL does require more support resources, for the senior design course at the USD there are such resources and they would probably not be effectively used elsewhere if not used for senior design. Thus the rating for support resources for PjBL and subject + PjBL was in between those of PBL and subject or subject + cooperative. The institution prioritizes effective teaching and thus less effective methods like pure subject-based learning are not preferred.

The same factor weighting pairwise comparison chart from Table 3 was used here.

Comments: as seen in Table 6, PjBL has the highest score. The optimal nature of PjBL is supported by the PDM as shown in Table 6 where PjBL is the preferred pedagogy; i.e. it has the highest score of 93% compared to the next highest of 59 and 57%. The score of 93% is clearly highest whereas 59 and 57% are probably not distinguishable given the precision of this matrix. Senior design is a course where there is general agreement among educators regarding the basic pedagogical approach. Although engineering educators differ widely in their implementation of PjBL including factors such as industry involvement, cost, type of project and length of the project [32], virtually all programmes use a project-based approach. There are no known reports advocating teaching senior design as a subject-based course. Since the results of this tool agree with common knowledge and practice in this area, this supports the concurrent form of criterion validity [33] for the PDM. By inspection, the PDM also has face validity.

USEFULNESS OF THE PEDAGOGY DECISION MATRIX

Case study: statics

Based on the example shown in Figs. 4 and 5,

Table 6. Pedagogy decision matrix for senior design course

	Pedagogies				
	Subject-based learning	Subject + project	Subject + cooperative	Problem-based learning	Project-based learning
A: Students (a = 25%)					
A1 Self direction	1	3	2	5	5
A2 Willingess to accept	1	2	2	3	5
A3 Class dynamics	2	3	2	5	5
Subtotal	4	8	6	13	15
% score A	27	53	40	87	100
B: Instructor (b = 33%)					
B1 Skills	3	4	3	2	5
B2 Risk tolerance	1	2	1	2	4
B3 Time	2	2	2	1	3
Subtotal	6	8	6	5	12
% score B	40	53	40	33	80
C: Course (c = 33%)					
C1 Learning objectives	1	2	1	4	5
C2 Future implications	1	3	2	4	5
C3 Pedagogy resources	4	4	4	1	5
Subtotal	6	9	7	9	15
% score C	40	60	47	60	100
D: Institution (d = 8%)					
D1 Tenure expectation	1	3	2	4	5
D2 Support resources	5	4	5	3	4
Subtotal	6	7	7	7	9
% score D	60	70	70	70	90
Total (aA + bB + cC + dD)	38	57	45	59	92

subject + project-based learning should be a well-suited pedagogy for statics. One of the authors implemented this pedagogy for a statics class of 21 students (http://home.sandiego.edu/~dmalicky). A team-based Balsa Bridge design/build/test project was selected because it addresses core learning objectives, typically improves student enthusiasm, has some existing pedagogical resources and develops design, teamwork and hands-on skills. The course was organized by subject-based learning, while the project was introduced in stages corresponding to relevant topics. The last two weeks of the course were largely devoted to bridge construction. Student enthusiasm was quite high throughout the project. Most students had sufficient self-direction to handle the project with normal levels of guidance. The instructor's existing skills and experience were well suited to implement the project and coordinate teams, although the time required proved to be more than anticipated; future implementations would be less demanding. There are numerous implementations and resources for Balsa Bridge projects on the Web [34], although these are typically high-school level and were only partially helpful in the development of an engineering student project.

Students achieved impressive loads from their approximately half-pound bridges: most held more than 500 lb with a maximum of 1648 lb. On the end-of-course survey, students rated the course overall at 4.3 (1–5 scale) and most students commented on the importance of the Bridge project towards their learning. For example, according to one student:

> Building a bridge and facing challenges with a group contributed most to my learning. This was stuff a textbook could not teach.

Incorporation of the project allowed teaching to a broader set of learning styles and to higher levels of Bloom's taxonomy. Accordingly, this allowed incorporation of a design problem on the final exam, for which the overall average was 83%. The project required little outside support from the University.

Based on this experience, it appears the PDM provides a good representation of the advantages and disadvantages of a pedagogical choice. The lowest ratings in the Subject + Project column of Table 5 were for Time (B3) and this did prove to be the primary disadvantage of the chosen pedagogy. Such correspondence illustrates how the PDM can inform the implementation strategy for whatever pedagogy is chosen: the instructor would have been wise to reduce other departmental duties while developing a time-demanding pedagogy. Further, in the Problem-based learning column of Table 6, time demands (B3) were predicted to be a 1. Using the current experience with subject + PjBL as a baseline, this indicates that a substantial reduction in other duties would have been necessary to implement PBL. The PDM for this course rated subject-based learning relatively low (Table 5). Indeed, a number of instructors noticed that student enthusiasm was higher than in prior semesters teaching Statics without the project.

Overall curriculum

If applied to all courses within a given programme or department, this tool could be used to assess which courses would benefit most from a change in pedagogy while using the least resources. Similarly, the PDM could enhance the ABET process and continuous improvement [35]. By considering which pedagogies would be most suited to which courses and instructors for a given set of students at a given institution, engineering educators could make strategic decisions about which courses to focus improvement. The tool could also be expanded to focus on a sequence of courses.

Instructor reflection

The process of filling out the PDM for a particular course may be beneficial for the instructor. Although the process takes a fairly short time, it can shed light on challenges associated with a particular pedagogy or highlight areas where the instructor will need to spend additional time or resources to be successful. This could guide an instructor in implementation strategies and resource allocation. For example, if an instructor goes through this process and decides to implement PBL, looking back at the factors where PBL was rated high gives good justification for this choice and factors where PBL was rated low show where the instructor needs to focus energy. The statics case study discussed earlier in this section demonstrates the validity of this guidance.

CONCLUSIONS

In this paper, we have presented the PDM to assist engineering educators in choosing an appropriate pedagogy from among many possibilities. This tool uses the methodology of engineering decision analysis including factors related to students, course, instructor and institution along with appropriate weightings. Examination of these factors assists instructors in evaluating the benefits and risks of a particular pedagogy for their particular situation. In addition, the PDM helps the instructor identify an effective strategy to implement the chosen pedagogy. We provided examples of the application of this tool to several engineering courses across different disciplines and levels of undergraduate students. Examples of the usefulness of the PDM include enhancing a specific course, process for continuous improvement of the curriculum, optimizing of allocation of resources particularly faculty course development time and instructor self-reflection.

Clearly, traditional and non-traditional pedagogies both have advantages and disadvantages. Active/engagement pedagogies have significant potential for enhancing student learning. While active engagement pedagogies may not always be optimum for all engineering courses, use of the PDM demonstrated that it is generally desirable to incorporate some active learning components. Many authors advocate starting small and building slowly [16, 29]. Felder [29] cautions that if instructors:

> . . . try to implement every new technique they hear about, they will probably be overwhelmed by the time the find themselves spending and the student resistance they encounter, get discouraged and go back to old ways of doing things. Instead, they are advised to select only one or two ideas at a time and try them long enough for the students to acclimate to the new methods . . .There is no hurry. (p. 3)

We believe that the optimum pedagogy varies according to situational factors. Given the various available options and the many situation-specific factors, the selection process can be confounding, if not intimidating. The PDM provides the engineering educator with a systematic framework for choosing an optimal pedagogy, addressing the practical question of how and what teaching method to choose.

REFERENCES

1. The Engineer of 2020: Visions of engineering in the new century, *National Academy of Engineering*, 2004.
2. Assessing the Capacity of the U.S. Engineering Research Enterprise to Meet the Future Needs of the Nation, *National Academy of Engineering*, 2005.
3. *The Journal of Engineering Education,* Review Issue, **94**(1), 2005.
4. I. J. Busch-Vishniac and J. P. Jarosz, Can diversity in the undergraduate engineering population be enhanced through curricular change? *Journal of Women and Minorities in Science and Engineering Education*, **10**, 2004, pp. 255–281.
5. M. R. Borrego, Streveler, N. Chism, K. Smith and R. Miller, Developing an engineering education research community of practice through a structured workshop curriculum, *Proceedings of the ASEE Annual Conference*, (2006).
6. D. Malicky, M. Huang and S. Lord, Problem, project, inquiry, or subject-based pedagogies: what to do? *Proceedings of the 2006 ASEE Conference*, (2006).
7. M. Huang, D. Malicky and S. M. Lord, Choosing an optimal pedagogy: a design approach. *2006 Frontiers in Education Conference*, San Diego, CA, October 2006.
8. K. A. Smith, S. D. Sheppard, D. W. Johnson and R. T. Johnson, Pedagogies of engagement: classroom-based practices, *Journal of Engineering Education*, **94**(1), 2005, pp. 87–101.
9. Z. Kou and S. Mehta, Lessons learned from incorporating problem-based learning and Lego systems in engineering measurements laboratory, *Proceedings of the 2005 ASEE Conference*, (2005).
10. K. J. Nasr and B. Ramadan, Implementation of problem-based learning into engineering thermodynamics, *Proceedings of the 2005 ASEE Conference*, (2005).
11. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education,* **93**(3), 2004, pp. 223–231.
12. D. R. Woods, *Problem-based learning: how to gain the most from PBL*, (1994). http://chemeng.mcmaster.ca/pbl/
13. J. C. Perrenet, P. A. J. Bouhuijs and J. G. M. M. Smits, The suitability of problem-based learning for engineering education: theory and practice. *Teaching in Higher Education*, **5**(3), 2000, pp. 345–358.
14. J. E. Mills and D.F. Treagust, Engineering education—is problem-based or project-based learning the answer? *Australasian Journal of Engineering Education*, 2003, pp. 2–15, http://www.aaee.com.au/journal/2003/mills_treagust03.pdf
15. A. Carlson, Using problem based learning to teach thermodynamics: the good, the bad and the ugly, *Proceedings of the 2005 ASEE Annual Conference*, (2005).
16. D. R. Brodeur, P. W. Young and K. B. Blair, Problem-based learning in an aerospace engineering education, *Proceedings of the 2002 ASEE Conference*, (2002).
17. M. J. Prince and R. M. Felder, Inductive teaching and learning methods: definitions, comparisons and research bases, *Journal of Engineering Education,* **95**(2), 2006, pp. 123–138.
18. D. E. Kanter, H. D. Smith A. McKeenna, C. Rieger and R. A. Linsenmeier, Inquiry-based laboratory instruction throws out the 'cookbook' and improves learning, *Proceedings of the 2003 ASEE Conference*, (2003).
19. National Research Council, *How people learn: brain, mind, experience and school.* National Academies Press, (2000). http://www.nap.edu/books/0309070368/html/
20. National Research Council, *Inquiry and the national science education standards: a guide for teaching and learning*. National Academies Press, (2000). http://www.nap.edu/books/0309064767/html/
21. R. M. Felder, D. R. Woods, J. E. Stice and A. Rugarcia, The future of engineering education. ii. Teaching methods that work, *Chemical Engineering Education,* **34**(1), 2000, pp. 26–39. http://www.ncsu.edu/felder-public/Papers/Quartet2.pdf
22. L. Jamieson, W. C. Oakes and E. J. Coyle, EPICS: serving the community through engineering design projects, in *Learning to Serve: Promoting Civil Society through Service Learning*. L. A. K. Simon, M. Kenny, K. Brabeck and R. M. Lerner, (eds), Kluwer Academic Publishers, Norwell, MA, (2001).
23. R. Altman, Higher education and psychology in the millennium, *American Psychologis*t, **51**(4), 1996, pp. 371–378.

24. E. Tsang (ed.), Projects that matter: concepts and models for service-learning in engineering, AAHE's Series in *Service-Learning in the Disciplines,* American Washington, DC: Association for Higher Education, (2000).
25. M. Z. Huang, The catapult experience, *Proceedings of 2001 ASEE Annual Conference*, (2001).
26. S. M. Lord, Cooperative learning homework teams in a materials science lecture course, *Proceedings of the 2001 ASEE Annual Conference*, (2001).
27. R. Fruchter and S. Lewis, Mentoring models in support of P^5BL in architecture/engineering/ construction global teamwork, *International Journal of Engineering Education,* **19**(5), 2003, pp. 663–671.
28. M. J. Cline and G. J. Powers, Problem based learning in a chemical engineering undergraduate laboratory, *Proceedings of the 1998 ASEE Conference*, (1998).
29. R. M. Felder, J.E. Stice and A. Rugarcia, The future of engineering education. VI. Making reform happen, *Chemical Engineering Education,* **34**(3), 2000, pp. 208–215.
30. C. L. Dym and P. Little, *Engineering Design: A Project-Based Introduction, 2nd edn,* Wiley, (2004).
31. N. Howe and W. Strauss*, Millennials Rising: The Next Great Generation,* New York, Vintage Books, (2000).
32. J. Wilbarger and S. Howe, Current practices in engineering capstone education: further results from a 2005 nationwide survey, *2006 Frontiers in Education Conference*, San Diego, CA, (2006).
33. W. B. Walsh, N. E. Betz, *Tests and Assessment*, Prentice Hall, (2001).
34. Example Balsa Bridge websites: http://www.balsabridge.com/, http://cl.k12.md.us/bridges/bridgept.htm, http://www.garrettsbridges.com/
35. http://www.abet.org/forms.shtml

David M. Malicky is an Assistant Professor of Mechanical Engineering at the University of San Diego. His teaching interests are in solid mechanics, design and manufacturing. His research interests include biomechanics and engineering education. He received a BS from Cornell University and a Ph.D. from the University of Michigan in Mechanical Engineering and an MS in Counseling Psychology from the University of Kansas.

Susan M. Lord received a BS from Cornell University and the MS and Ph.D. from Stanford University and is an Associate Professor of EE at the University of San Diego. Her teaching and research interests include electronics, optoelectronics, microwave photonics, materials science and first year engineering courses. She served as the General Co-Chair for the 2006 Frontiers in Education Conference. She and several colleagues won the 2004 Helen Plants award for Best Non-traditional Session at FIE2004 for 'Feminist Frontiers'.

Ming Z. Huang is currently Associate Professor of Mechanical Engineering at the University of San Diego, San Diego, California. Dr Huang is a registered Professional Engineer and is actively involved in research focusing on integrating industry practices with engineering education. Dr Huang received his BS from the National Taiwan University in Taipei, Taiwan in 1980, MS from the University of Rhode Island in Kingston, Rhode Island in 1984 and Ph.D. from the Ohio State University in Columbus, Ohio in 1988, all in mechanical engineering.