2006-1771: PROBLEM, PROJECT, INQUIRY, OR SUBJECT-BASED PEDAGOGIES: WHAT TO DO?

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Abstract

When trying to determine the most effective approach for enhancing student learning, engineering educators may feel overwhelmed by the myriad of pedagogies and variety of results presented in the literature. One may choose from a wide and potentially confusing array of teaching methods including problem-based learning, project-based learning, inquiry-based learning, subject-based learning, active learning, cooperative learning, mixed methods, and others. Both new and experienced instructors may be appropriately hesitant to risk a new approach, but also unsure of how to evaluate or manage that risk. In this paper, we will briefly describe the pedagogies of project-based learning, inquiry-based learning, subject-based learning, and mixed methods. We will then discuss a framework by which an engineering educator could evaluate the potential benefits and risks of adopting a particular pedagogy in a specific course. This is done by identifying factors relating to students, instructor, course, and institution. While there is no one universal best choice, this paper will examine the merits, risks, and implementation strategies of various pedagogies as they relate to these factors.

Introduction

New or experienced engineering educators may have a sincere desire to enhance student learning but not be sure how to approach this task. Although engineering educators may have some understanding of active learning, cooperative learning, and problem-based learning, 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 may require 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 covary with many situation-specific factors such as the instructor's tenure status and students' prior expectations. One thesis of this paper is that traditional and non-traditional pedagogies both have advantages and disadvantages. To help the educator address these difficult decisions, this paper aims to 1) provide an overview of the major pedagogical options for engineering courses and 2) delineate the major situational factors that influence the risks, benefits, and implementation strategies of these pedagogies.

Overview of pedagogies

This paper does not provide detailed guidance towards implementing any particular pedagogy. Rather, a brief overview is given and appropriate references cited.

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 much more amenable to achieving subject-based course objectives while 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 lab 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 lab 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 like engineering. Cookbook labs are most appropriate for training on equipment and procedures but is not optimal for deep learning or retention of concepts.

- Groupwork: Students work together on a project in groups typically assigned by the instructor. Besides doing so out of the necessity of limited resources, the motivation for the instructor including groupwork is often a desire 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

There has been considerable interest in the profession and discussion in the engineering education literature on more active pedagogies or "pedagogies of engagement"[1]. The motivation for much of this work has been that the traditional ways of teaching engineering have not achieved the results in terms of student learning (particularly for skills such as teamwork and communication) and diversity that satisfy most engineering educators and employers. In this paper, we interpret "active/engagement pedagogies" to mean pedagogies which encourage students to be active participants in shaping their learning inside and outside the classroom. We will briefly describe the pedagogies of engagement that we believe have the most relevance for engineering education.

- Problem-Based Learning (PBL): The motivation and organizing principle for a problem-based course is a set of carefully selected open-ended problems. The problems are chosen by the instructor such 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-centered 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. Teachers function as facilitators of this process. The theoretical basis for this pedagogy is that it is relatively similar 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[2,3,4,5]. However it is somewhat controversial; criticisms include 1) "PBL may not always lead to constructing the 'right' knowledge" (Perrenet[6], in Mills[7], p. 7), 2) PBL results in little or no improvement on exam scores[4,8], and 3) PBL may lead to lower teacher ratings[8]. Some implementations of PBL provide significant prepared guidance from the instructor[3] and this appears to improve student acceptance. For the curriculum as a whole, Brodeur[9] recommends a progressive implantation of problem-based learning: "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[3,4,5,8,10].

- Project-Based Learning (PjBL): similar to problem-based learning, 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 Problem-Based Learning 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[7], and 3) accompanied by subject-based courses. Typical deliverables from PjBL include technical reports, presentations, and physical artifacts. The distinction between project- and problem-based learning 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 project-based learning 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 most commonly used in labs. Students observe a carefully selected phenomenon, develop 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 student-centered, interactive with peers, and relatively self-directed. Teachers function as facilitators. Inquiry learning typically requires less student initiative than problem-based learning 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 labs and fully open inquiry learning, for students who may not yet have sufficient scientific skills[10]. Structured/guided inquiry also carries fewer demands of equipment and instructor time, though more so than cookbook labs. There is considerable evidence that the inquiry pedagogies increase critical thinking skills and depth of understanding of concepts[10,11,12,13].

- Cooperative & Collaborative Learning: Cooperative learning and collaborative learning are two popular terms used to describe modern engineering education. They both describe a learning environment where students work together towards a common learning goal. Often the two are used interchangeably though they are not identical. As described by Karl Smith et al[1], 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[4]. Felder[14] 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. Individual accountability is not a necessary element of collaborative learning. 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. Cooperative learning could overlap with project-based learning if the students work in structured teams on the project including some group processing. Cooperative learning could overlap with problem-based learning if students work together in cooperative learning teams. Most problem-based learning is done in teams in engineering and so would be collaborative or cooperative learning depending on how the teams are structured[1,4,14]. When engineering educators use the terms cooperative or collaborative learning, they are usually distinguishing their efforts from traditional groupwork 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 service-learning, 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) program which began in 1995 and has now spread throughout the U.S.[15] (http://epics.ecn.purdue.edu/). Service-learning often overlaps with project-based and/or cooperative learning as it can be structured around a team project for a community customer such as a school or nonprofit organization. Service-learning has been shown to have many beneficial effects for students particularly in terms of ABET criterion such as social and global impact especially if it is structured to encourage development of "socially responsive knowledge"[16]. Service-learning encompasses a wide range of experiences even within engineering and are 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 freshman through senior year work together to develop toys for disabled children or to improve access to social services for at-risk children[17].

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.

<u>Subject + Project-Assisted:</u> This type of course includes at least one group project. For example, a sophomore Statics class where students design and build a balsa bridge in the last few weeks or a junior electronics class where students design and build a feedback amplifier in the last few weeks. 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 artifact to demonstrate principles of design and optimization[18].

<u>Subject + Cooperative:</u> This type of course includes some sort of 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.

Situation-specific factors

Smith[1] poses this question: "Are some types of engineering classes (freshman or senior, lectures or project-based or labs, 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; this paper begins to address factors such as these. 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 in this paper 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.

- <u>Student capacity for self-direction:</u>
    - 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 problem-based learning 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 nontraditional 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 are they ok with the instructor functioning as a guide-on-the-side? Are they ok with covering 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 nontraditional pedagogies have they experienced before? If they have had good (or bad) experience with a nontraditional pedagogy before, they are likely 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 are 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 the instructor to self-assess their 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[8,19]? Or, does the instructor need to improve their 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[20] 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[19] 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, PjBL, open inquiry learning, and service-learning courses.
    - 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, PjBL, or inquiry learning will certainly require a lot of extra time. If an instructor is just beginning to develop new materials, perhaps it would make sense 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:

- Foundation or advanced: Is the course a pre-requisite for more advanced courses, which require full breadth of coverage in the foundation course? While PBL, PjBL, and inquiry learning 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.

- Theory or applied: Some authors hold that PBL and PjBL pedagogies are more suited for applied courses and that the subject-based format is a good choice for theory[2,19]. But, it is well established that active and cooperative learning enhance understanding for theory courses[1,4]. This subject + cooperative mixed method is recommended instead of a purely subject-based lecture format.

- Laboratory: The cookbook lab pedagogy provides clearly defined equipment needs and relatively close control over equipment use. Less structured laboratory formats such as PBL, PjBL, or full inquiry-based learning tend to require a wider range of equipment over less predictable time periods, and have more risk of equipment damage[19]. Additional equipment, budgets, and support staff are probably needed to support such pedagogies for laboratories. Guided inquiry provides a compromise for equipment requirements.

- Pedagogical resources: Are there pre-existing resources to guide implementation of a nontraditional pedagogy for a particular course, such as published implementations or experiences from colleagues? The *ASEE Proceedings* record a number of such implementations[2,8,11].

Institution

- Tenure expectations: Does the institution prioritize teaching, in which case use of nontraditional pedagogies would likely be expected, or research, in which case some pedagogies would be more difficult to implement due to time requirements?

- 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 your efforts?

- Campus climate: Is innovation encouraged or is maintaining status-quo expected?

- Unique feature: Are there local cultural attributes or requirements that would influence pedagogical decisions?

Conclusions

The above factors provide a comprehensive set of questions to evaluate the benefits and risks of a particular pedagogy for a particular course, instructor, institution, and set of students. The characteristics of these factors will also influence the type of strategy to implement the chosen pedagogy for a particular course. The "equation of suitability" is highly non-linear, with a number of interaction effects between factors and pedagogies: e.g., student capacity for self-direction is very important for problem-based learning while considerably less so for cooperative learning. This variable level of factor importance (pedagogy x factor) is a subject for further research.

One thesis of this paper is that the optimum pedagogy varies according to situational factors. However, certain generalizations appear to be valid. Generally, new engineering educators would be advised to first look at the more established pedagogies and mixed-methods. These methodologies have been successfully used by a number of effective educators and do not have excessive risk or time requirements[20]. They are "safe and effective." For new laboratory courses, structured/guided inquiry is relatively smooth running but requires somewhat more time for course development than a cookbook lab. For existing lab courses, structured/guided inquiry may be introduced in a few labs per term without excessive demands. Project-based learning is effective, though carries increased risks for the new engineering educator due to time, equipment, logistics requirements; starting small is advised. Full problem-based learning appears to carry the most risk and thus caution is advised for the new engineering educator[8].

Many authors advocate starting small and building slowly[9,20]. Felder[20] 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)

Active/engagement pedagogies have significant potential for enhancing student learning. This paper provides a framework to guide engineering educators in choosing suitable pedagogies from among the myriad of possibilities.

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