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Work in Progress: A Taxonomy for Faculty Scaffolding of Project-based Learning

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John McNeill received his bachelor's degree from Dartmouth College in 1983, M.S. from the University of Rochester in 1991, and Ph.D. from Boston University in 1994. From 1983 to 1990 he worked in industry in the design of high speed, high resolution analog-to-digital converters and low noise interface electronics used in wide dynamic range imaging systems. In 1994, he joined Worcester Polytechnic Institute, in Worcester, Massachusetts, where he now is Professor and Dean of Engineering. In 1999 he received WPI's Award for Outstanding Teaching, and in 2007 was one of the inaugural winners of WPI's Exemplary Faculty Award.

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Rick Vaz is Inaugural Director of WPI's Center for Project-Based Learning, which helps colleges and universities advance student project work across the curriculum. From 2006 to 2016 Rick served as WPI's Dean of Interdisciplinary and Global Studies, overseeing a campus wide interdisciplinary research requirement and a worldwide network of 46 centers where more than 900 students and faculty per year address problems for local agencies and organizations. He has been a Senior Science Fellow with AAC&U and in 2016 received the National Academy of Engineering's Bernard M. Gordon Prize for Innovation in Engineering and Technology Education.

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Larry Seow researches, lectures and initiates methods of design and thinking for encouraging critical creative process to drive future readiness, forming new innovative mind-set for individuals and groups from different disciplines, to maximize their resourcefulness with clarity in having solutions, to seize opportunities and keep complex problems away in the ever changing volatile, uncertain, complex and ambiguous environment.

Larry is one of four master trainers at the pre-planning meeting for the 2nd design thinking for Public Service Division, Prime Minister's Office, Singapore; and co-lead the creative thinking led workshop in Public Sector Innovation for Productivity Programme in the Civil Service with the Ministry of Manpower Indonesia, with focus on Human Resource (Progressive HR) and Technical Education.

He has participated in workshops with the Architecture Department of Tokyo National University of Fine Arts & Music, Japan; and urban renewal workshop with The Crisis Design Network in Beppu, Japan. He served as senior facilitator for two national conversation initiative; Aspire 2014 (Applied Study in Polytechnics and ITE Review) and OSC 2012 (Our Singapore Conversation). His commercial design works are commissioned for show houses in Singapore and Jakarta; it includes the Lady Hill, Parc Emily, Springside, The Loft, The Edge, The Colonnade, City Harvest Church, PSA Building, Pakuwan Berlain Residence, PT Wiranusa Grahatama and Nusa Dua, the Westin Resort in Bali.

The research interests were exhibited in the medium of photography, drawings and installations. Selected group show titled Singapore, at the Delft Centre, the Netherlands and Design Nation, College of Fine Arts, UNSW, Australian High Commission, Design Life Bali, RMIT University, GAYA Art Space, Ubud, Bali, Indonesia, Alphabet Soup in Alliance Francaise, SG Private Banking. Photography exhibition, MICA Building. INDEX.s 2000, Sculpture Square. Singapore Slice, Earl Lu Gallery and Reconstruction of a City, at the St James Power Station.

Notable awards by his students were the Silver Lion Prize at the prestigious Cannes Lions competition, and the Yellow Pencil at the distinguished D&AD awards.

Awards and recognition received by Larry includes the Singapore Ministry of Education – Tertiary Education Research Fund; Gold Award for short film at the Crowbar Awards; Outstanding Photograph award at the Young Photographers Network; 1st Leadership Development Course endorsed by the Permanent Secretary (Education Policy) of the Ministry of Education Singapore; and is the winning team member for the Best Idea Award at the Design Olympiad, conducted by the Royal College of Art Helen Hamlyn Centre with Seoul Design Foundation.

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WIP: A Taxonomy for Faculty Scaffolding of Project-Based Learning Experiences

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1 Introduction

Project-based learning (PBL), recognized as a high-impact practice [1, 2], is an increasingly common feature in US engineering programs, with implementations ranging from first-year experiences through capstone design projects. The Buck Institute of Education, whose work focuses mostly on K-12 education, has articulated a set of essential elements of "Gold Standard PBL" [3] that are readily applicable to the higher education context:

1. *Key Knowledge, Understanding, and Skills*: Make clear the learning goals for PBL assignments. Often these are a combination of disciplinary knowledge and transferrable skills and abilities.
2. *Challenging Problem or Question*: Engage students with a driving problem or question with a suitable level of challenge and open-endedness.
3. *Sustained Inquiry*: Plan for an extended period to allow students to learn new topics and explore issues in some depth.
4. *Authenticity*: Motivate students with problems that connect to applications in the world around them.
5. *Student Voice & Choice*: Provide students with opportunities to select goals, approaches, and/or evaluation procedures for their work.
6. *Reflection*: Provide opportunities for students to reflect on their learning, consider what they might have done differently, and connect learning to future work.
7. *Critique & Revision*: Scaffold PBL with interim assignments, and provide formative feedback for improvement.
8. *Public Product*: Make student work evident beyond the classroom; external audiences for their work powerfully motivate student achievement.

Pfeifer and Spanagel [4] describe how PBL calls upon faculty to "re-envision" their roles as educators, and point out that this adjustment can be uncomfortable for faculty whose own training featured more conventional pedagogy. Faculty new to PBL can find themselves out of their comfort zones, and may struggle with questions such as how much guidance to provide and how much freedom students can handle.

This paper explores a simple taxonomy to help instructors using PBL to be reflective about their teaching, and match their style of interaction to the needs of students at different stages of their learning. Section 2 explores some of the challenges faculty face in delivering PBL that motivated the development of the taxonomy described in Section 3. Sections 4 and 5 describe case studies of the taxonomy as applied to practice at Worcester Polytechnic Institute and Nanyang Polytechnic Institute.

2 Challenges for Instructors Using PBL

High-impact practices involving active and collaborative learning such as PBL have been shown to have positive effects on such learning outcomes as critical thinking [5]. However, the quality of PBL implementation and support that faculty provide is a crucial factor in its efficacy. Successfully implementing PBL requires that faculty address multiple challenges:

2.1 Time Scales

PBL can take place over different time scales - as short as hours (contained in one class meeting or afternoon lab session) or as long as a semester or academic year (as in capstone design). Several of the gold standard PBL elements (challenging open-ended problem, sustained inquiry, student choice, reflection, revision) require time to play out. How should faculty balance the benefits of an open-ended experience with the time-limited nature of constrained academic schedules?

2.2 Student Backgrounds and Project Learning Objectives

Students have varying prior experiences, capabilities, and needs, and some students will need more guidance and structure than others. Faculty should consider the level and background of their students to gauge the appropriate level of structure for PBL experiences. Faculty also must consider the role of the course or project in the curriculum; a developmental course early in the curriculum is likely to have very different educational objectives than a capstone course, both in content and process.

2.3 Instructor Background

Many engineering faculty have been trained primarily for research, and may not have much experience in the sort of engineering project management that PBL can involve. Faculty steeped in traditional lecture-driven approaches in engineering emphasizing "content delivery" are likely to struggle with a sense of loss of control when introducing PBL experiences that involve students learning by doing, rather than by being told. Despite considerable evidence that active learning strategies benefit most students, faculty understandably are uncertain regarding how much time and attention to devote to the process elements that are fundamental to PBL.

2.4 Student Teamwork

There are many good reasons to employ student teams for PBL experiences - student teams can gain valuable collaboration skills, are able to tackle more interesting and complex problems, and make PBL more practical in large-enrollment courses. However, teamwork can create significant challenges for students and faculty alike unless students are given guidance and processes to support effective and equitable teamwork. The amount of structure needed, of course, depends on the students' previous experiences in team settings.

3 Taxonomy

Faculty understandably seek to adopt "best practices" for advising projects. However any effort to develop a unified best practices model for all projects is unrealistic given the diversity of challenges described in section 2. What we propose instead is a model based on student capability, instructor interaction, and experiential goals of the project. Figure 1 shows a taxonomy of advising styles organized by two dimensions:

- Instructor involvement, on a continuum from passive to active
- Learning goal of the project experience, on a continuum from product to process

As will be seen in the case studies described in sections 4 and 5, the taxonomy of Figure 1 is an organizing principle to give a language for instructors using PBL to describe their interactions with

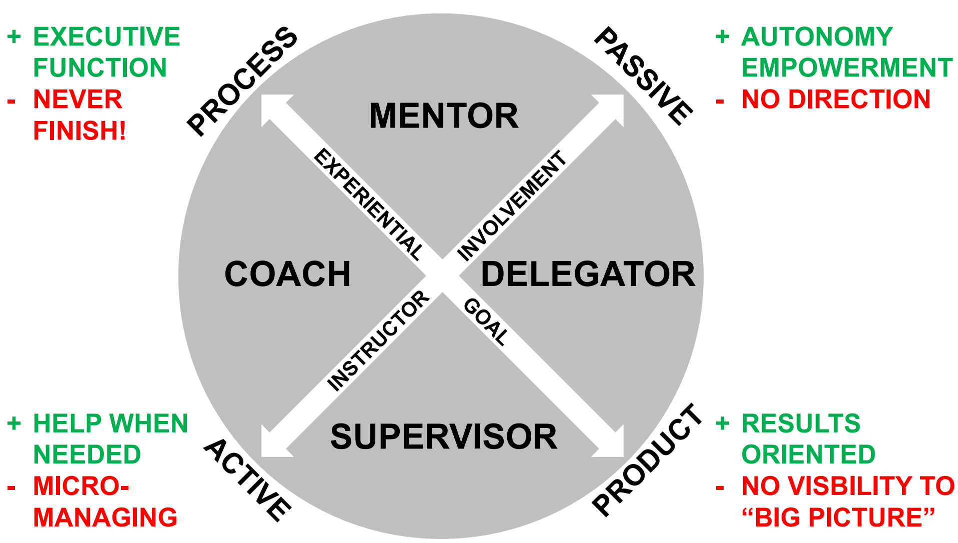

Figure 1: Taxonomy of advising styles (active ↔ passive), experiential learning goals (product ↔ process), and advisor roles.

students, and to help instructors be reflective and aware of how their style of interaction is appropriate to the needs of the students and the goals of the project experience.

It should be noted that, as indicated in the figure, each emphasis in approach can affect learning in a positive or negative manner depending on the student and project environment. Specifically:

Instructor involvement: While the terms "active" and "passive" may have good or bad connotations for a particular advisor, it should be emphasized that either approach can have a positive or negative effect depending on student needs. For example, strong students may experience a close interaction negatively as micromanagement, whereas a more hands-off approach might be experienced positively as the instructor empowering students. Similarly, students who are not as capable would be more likely to appreciate close interaction as a positive sign of faculty who care to help students when they need assistance; a less interactive instructor might be seen in a negative light as distant and uncaring.

Experiential goal: Students in PBL need to achieve both product and process learning. Public product is a key part of PBL, so it is important to "get something done." And for an authentic experience that students have had a voice in choosing, they will want to finish and see impact. But the process aspects of PBL - critical thinking, problem solving, collaboration, self-management, reflection - are also important and require time to play out. Instructors who are excessively focused on product (say, from a results-oriented research productivity mindset) may be overly prescriptive in defining student activity, achieving results but depriving students of the important "big picture" project process experience. Conversely, instructors who overemphasize process may help students develop higher level executive function, but the students may never actually complete the project.

While styles and goals in Figure 1 are expressed along a continuum, at the extremes we can identify four archetypical advisor roles:

Supervisor: Active advising, product oriented. Most appropritate to students early in their development, needing frequent support and the motivation of a readily visible goal.

Coach: Active advising, process oriented. For students who have the technical knowledge needed in their discipline, but needing guidance in the project process to achieve their goal.

Delegator: Passive advising, product oriented. For more advanced students who are able to complete a task once it is defined for them.

Mentor: Passive advising, process oriented. For the most advanced students, who are able to make progress and learn best when working independently, needing only occasional guidance on process aspects.

4 Case Study: Worcester Polytechnic Institute

At Worcester Polytechnic Institute, students pursue a technical bachelor's degree over four years. As shown in Figure 2, each semester is divided into 7-week terms and students take three courses at a time; each course is equivalent to a 3-credit hour semester-long course. While PBL is integrated at various levels in many courses throughout the curriculum [6] there are three experiences dominated by PBL:

- First-Year Seminar
- Interdisciplinary Project
- Major Project

Following is a brief description of these three project experiences and their corresponding educational roles; Figure 3 shows the approximate range and evolution of advising styles appropriate to each.

First-Year Seminar: Six credit-hour experiences organized around "great problems" such as water, energy, food, education, and shelter. Students examine one of the world's most pressing problems from a range of perspectives (scientific, technical, economic, environmental, social, humanistic) and then work in small teams to research and propose solutions to a particular instance of the problem situated in a community. Learning outcomes include research skills, communication, collaboration, and critical thinking.

Educational roles: Students are typically novices at PBL, and may have little or no experience with independent learning and teamwork. Faculty provide considerable structure in the coach and supervisor roles, with frequent assignments and formative feedback. While students develop a report and poster presentation the emphasis is on development of transferrable skills.

Interdisciplinary Project: Nine credit-hour experiences in which small teams of students from different areas of study address an authentic, interdisciplinary problem involving both technical and social issues. Problems are typically posed by an external agency or organization, and students often complete them in a fulltime immersion away from campus. Students work under faculty direction to research the problem,

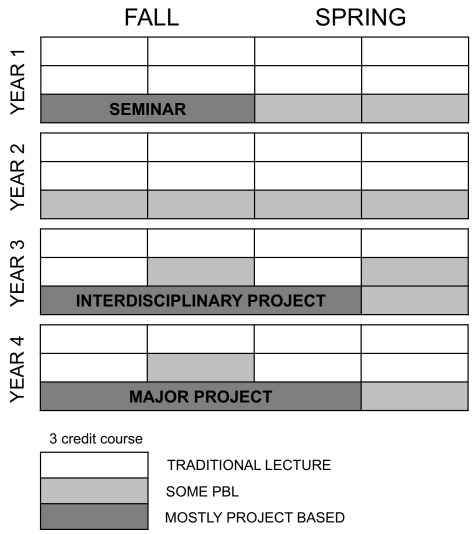

Figure 2: Project based learning experiences in WPI curriculum.

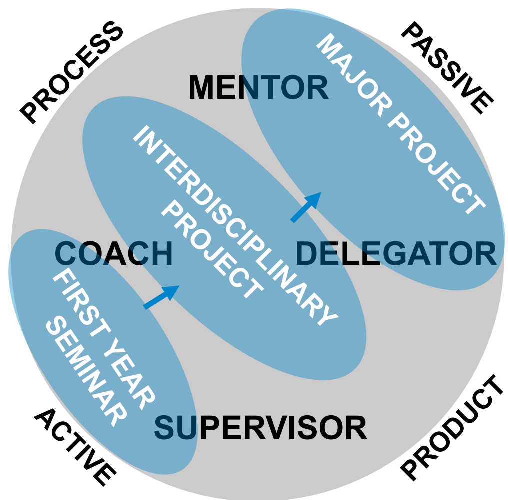

Figure 3: Typical evolution of advising styles in project based learning through WPI curriculum.

consider the needs of stakeholders, and develop a report and presentation describing their solution, which often takes the form of policy recommendations. Learning outcomes include research skills, contextual thinking, collaboration, communication, and problem solving.

Educational Roles: Students are typically new to intensive research and evidence-based writing, and also to interacting with stakeholders. In the coach role faculty provide a moderate amount of structure, with weekly assignments and meetings, and considerable formative feedback. Since the problems are usually authentic and impact a client, there is considerable attention to the quality of the result; however the delegator role is more appropriate than supervisor since learning outcomes emphasize transferrable skills rather than disciplinary content.

Major Project: Nine credit-hour experiences in which students tackle a challenge in their major area of study, typically in small teams. For engineering students, this might be a design project for an industrial sponsor, or it could be related to faculty research. Students apply knowledge and skills from across their program to implement a solution, typically developing an artifact or system. Learning outcomes include integration and synthesis of prior coursework, collaboration, communication, and problem solving.

Educational roles: Students are tackling a challenge similar to what they might face in an entry-level engineering job or graduate program, and are working in an area where they have considerable training. Faculty provide varying amounts of structure in the delegator and mentor roles, based on student needs and abilities. Considerable attention is paid to the quality of the result, and the extent to which it reflects the ability to apply knowledge in the major to an authentic problem.

To assess educational impact, WPI conducted a mixed-methods study of 38 years of alumni of the PBL-based curriculum [7]. Alumni attributed a wide range of professional skills and abilities as well as aspects of personal growth and broader world views to their formal project experiences. Interestingly, women reported more strongly positive impacts than men in 36 of 39 growth areas, suggesting that PBL could be an effective means for attracting and retaining women in engineering programs [8].

With regard to support of faculty development, all faculty are expected to engage in some form of PBL. WPI has featured a PBL-based curriculum for nearly 50 years, so the current faculty composition may reflect self-selection for comfort with project learning. It is notable that many faculty engage in interdisciplinary project work well outside their fields of expertise, some in immersive programs away from campus. Findings from a study of early-career faculty engaging in interdisciplinary off-campus project work suggests that such opportunities were seen as valuable personal and professional development experiences by the faculty, and that participation did not hamper progress toward tenure [9].

5 Case Study: Nanyang Polytechnic Institute

At NYP, students take a 3-year diploma program in a sequence of six semester-long 3-credit courses. Figure 4 shows how PBL experience is embedded in the curriculum; PBL currently forms about 30% of most diploma programs in NYP. In the first five semesters of the course of study, students are required to take one project module in each of the five semesters that deepens their skills in a specific key discipline. This is followed by a capstone project in the final semester and an industry internship. For industry internships, NYP works closely with companies so students are provided the opportunity to work on a "real world" project.

In order to equip the students with the necessary skills to solve complex multidimensional problems and to prepare them for a career in the future economy, NYP has embarked on an initiative to infuse interdisciplinary learning into PBL modules within the curriculum. Following is a brief description of the PBL experiences in years 1-3. Figure 5 shows the corresponding approximate range of advising styles appropriate to each.

Year 1 Projects: In Year 1, students are offered General Studies Modules (GSMs) which provide students with an understanding of policies and issues relating to Singapore's security, economy, and society. Students learn to recognize the unique advantages and constraints that shape Singapore's policies and development, and discuss different perspectives on contemporary issues. Particularly, they also gain appreciation of the social policies at work promoting equality, social cohesion and inclusivity. The students embark on learning journeys and field trips to gain an appreciation of human values and to develop empathy to social values. The students write reflection journals and do a group presentation at the culmination of the module.

Educational Roles: In the coach and supervisor roles, close interaction is provided to the students for this module, and assessment is geared more toward the learning process rather than the product. Assessment guidelines are generally more prescriptive, guiding students towards developing understanding and deepening of knowledge in selected domain areas. The GSM instructor also plays an active consultative role, meeting with the groups and checking on their progress regularly. This approach introduces students to the nuances of project work and aims to impart project management skills to the students.

Year 2 Projects: The learning outcomes in Year 2 require a deep mastery of domain skills by applying the concepts learned in the core modules. For an engineering project, such as development of a mobile plant watering robot, the students apply the knowledge learned in fundamental modules such as mathematics, mechanics and electronics to design and develop a working prototype. The assessments are integrated and test the student expertise in application of the knowledge. The assessment components also include teamwork, creativity and presentation skills.

Educational Roles: The module is delivered with more than one faculty to include multiple domains. The faculty act more in the coach and delgator roles; for example, directing the students to sources for relevant information. Regular consultation milestones ensure that the students meet the learning outcomes.

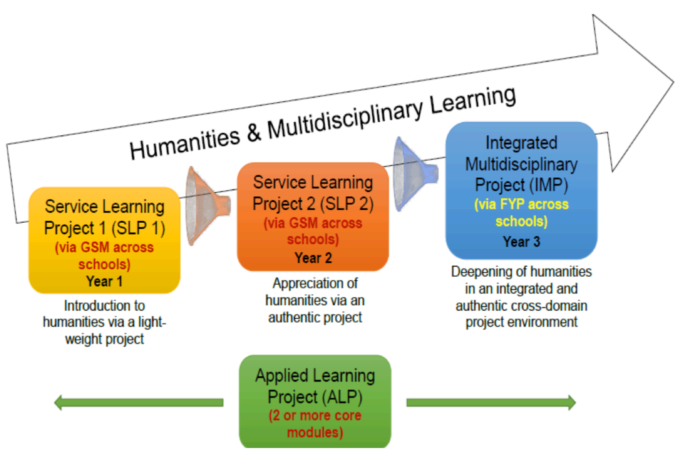

Figure 4: Project based learning experiences in NYP curriculum.

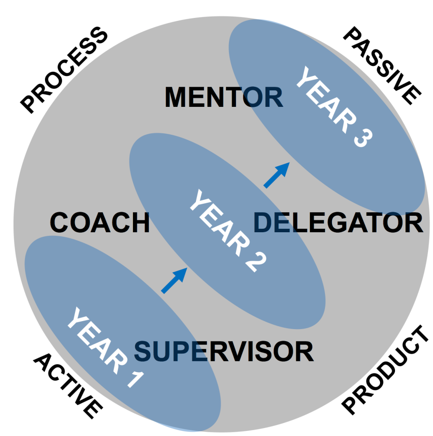

Figure 5: Typical evolution of advising styles in project based learning over years 1-3 of NYP curriculum.

Year 3 Capstone Project / Internship: In year 3, the Integrated Multi-disciplinary Project (IMP) program provides a platform for final year students from different disciplines to work in teams, conceive ideas based on real-life problems, propose plans for their capstone projects and develop these projects into working prototypes. Apart from the IMP programme, there are also staff-initiated projects that investigate the effectiveness of Transdisciplinary Project-Based Learning (TD-PBL) to teach research, innovation and enterprise-related modules across multiple disciplines. This program simulates a "real-world" environment for students from different disciplines to learn and apply "Design Thinking" and "Business Model" concepts.

Educational Roles: The project follows an iterative process from user experience (user desirability), problem solving (technology feasibility), and effective business model (business viability). As students mature in the program, they are more capable of work with progressively less interaction. Instructors act primarily in the delegator and mentor roles, as students work collaboratively to empathize, define, ideate, develop and test a prototype to solve a real world problem.

6 Conclusion

By considering dimensions of instructor involvement (passive to active) and learning goals (process to product), we have developed a taxonomy of roles for instructors in project-based learning experiences. Rather than indicating a single "best practice" of advising style, the taxonomy encourages instructor awareness of a broad range of student backgrounds and capabilities. Two case studies illustrate how the taxonomy promotes approaches tailored to different students and different types of projects across engineering curricula. This taxonomy could be helpful for faculty development by providing a framework within which faculty could be guided to design PBL experiences scaffolded by amounts of instructor support, involvement, and feedback that are developmentally appropriate to student needs and learning goals.

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