FOSTERING TEAM DYNAMICS ACROSS AN ENGINEERING CURRICULUM

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Abstract
Every year of the mechanical engineering CDIO curriculum at Ecole Polytechnique de Montreal contains an integrator project. To maximize team learning effectiveness, Ecole Polytechnique developed teaching strategies and tools so students can develop self-awareness, self-management, psychological diversity sensitivity and communication skills.

The yearly projects confront students with different forms of teamwork in an intense but gradual, dynamic but controlled experiential process. The project scenarios given to students are designed to create tense project situations. The team's reaction to this tension is influenced, in part, by each student's personality and interests. To generate controlled conflict situations in an educational context, Ecole Polytechnique developed team selection methods and tools. These tools are based on the Myers-Briggs Type Indicator™ [1] methodology supported by a Competence and Preference Sheet (CPS) developed by the teaching staff.

Over the four year program, students will challenge teamwork issues that grow in a planned progression. The final 4th year capstone project closely matches industrial realities and challenges including: multidisciplinary interactions, negotiation, budget and time constraints. This paper will discuss the use of the Myers-Briggs Type Indicator and the Competence and Preference Sheet (CPS) to foster effective team dynamics in student projects at Ecole Polytechnique de Montreal.

Keywords: Project-based learning, Team dynamics, Collaborative tools, transdisciplinary projects, Engineering psychological type.

Introduction
The importance of teamwork training in education appears clear when the greater context of project work in industry is put in focus. Project work has transformed from local intra-company groups to joining specialists from across the world in the completion of common projects. With globalized markets, all aspects of product design, engineering, development and manufacturing are affected by the migration of production facilities to better business opportunities abroad.

How can universities, through their training programs, prepare students to thrive in this changing reality?

Important engineering abilities are defined by the ABET Engineering Accreditation Commission Criteria [2]. Engineering programs must demonstrate that their students attain:

1. an ability to apply knowledge of mathematics, science, and engineering
2. an ability to design and conduct experiments, as well as to analyze and interpret data
3. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
4. an ability to function on multi-disciplinary teams
5. an ability to identify, formulate, and solve engineering problems
6. an understanding of professional and ethical responsibility
7. an ability to communicate effectively
8. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
9. a recognition of the need for, and an ability to engage in life-long learning
10. a knowledge of contemporary issues
11. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

It is implied by these criteria that students must understand the transmitted knowledge sufficiently to be able to use it in an industrial context after graduation. How can we verify and measure this understanding to confirm it is in fact usable knowledge? The integrator project progression leading to the 4th year capstone project gives students of Ecole Polytechnique the opportunity to demonstrate all these abilities and for educators to verify, in a project context, their level of understanding.

"Tell me and I forget. Show me and I may remember. Involve me and I will understand."
Confucius

In addition, the project context forces students to learn to manage and solve important real world project issues not specifically defined in the ABET criteria:

- Customer changes the product requirements late in the project
- Team members do not work or participate in the project as expected
- Choosing between different but equally viable solutions
- Upholding ethical professional values against imposed inadequate design choices
- Be challenged by uncertainty, doubt, chaos, compromise

Academic knowledge in most cases will not be sufficient, nor profound enough or just simply not yet acquired to complete all the proposed project tasks satisfactorily. This becomes an opportunity for students to use the training they received and acquire it permanently. It also provokes them to search for new concepts and knowledge on their own showing them the importance of self-motivated life-long learning efforts in their future professional careers.

Project curriculum progression

"No decision can be better than the questions posed" Larry Liefer, Stanford

To have students ask better questions and define better products we developed a continuous string of projects throughout the mechanical engineering curriculum. Each project's individual structure and integration with the other projects slowly develops specific aspects of project work with a hands-on approach (Table 1).

Year 1 4 months	MEC1201 Teamwork training	Variable team size depending on activities Short hands-on exercises in teams Experience teamwork challenges Learn to solve conflicts and team issues
Year 1 4 months	MEC1110 Project 1 Engineering practice	4 to 5 students per team Teaching staff defines teams Projects aimed at specific process steps Students change roles and responsibilities
Year 2 4 months	MEC2105 Project 2 Competition	5 to 6 students per team Students define teams Complete product development process Manufacturing of prototype required Students conserve a single role in team Team structure and management Working with a product specification
Year 3 4 months	MEC3900 Project 3 Individual	Complete product development process Student completes all project tasks alone Product needs definition required External mentorship relations
Year 4 8 months	MEC4340 Project 4 Capstone project	20 students per team Students define team structure and management 6 project subjects available Complete product development process Open-ended problems Multi-disciplinary work Manufacturing of specific components

Table 1. Project courses in engineering curriculum

The teamwork training in MEC1201 puts an emphasis on interpersonal communication (active listening, inferences) and teamwork (dynamics, roles, conflict management and norms) through in class experiential exercises and supporting theory. All mechanical engineering students (160/year) must follow this course. Through these exercises students develop better self-awareness that helps build cohesion and confidence in teams. They also develop their ability to give positive and critical feedback to other team members. A major effort is put on team member confidence building exercises and peer review critique tools.

The project course MEC1110 (Project 1) builds on the teamwork experiences given in MEC1201 (Teamwork training) and applies these abilities in experiential design projects. This is often the first time students' work in real project work that demands interdependence between team members doing different tasks in a common goal. The project scope is therefore defined so that students work on specific phases of the product development cycle, not a complete project. This controls the amount of design work required to a well established guideline so students can concentrate on using their teamwork skills in a project context. Team composition is defined by the supervising professor using the Competence and Preference Sheet (CPS) and previous educational institution. This selection process deliberately teams up students with differences in interests, background and competencies for both the technical and relational aspects. The team selection process sets the stage for students to experience first hand how humans often react differently within identical situations. The MEC1201 (Teamwork training) teacher participates in the MEC1110 (Project 1) project course as an external observer. Students are more comfortable discussing team problems with a person not involved in their project evaluation and they effectively use this opportunity to solve team issues.

In the second year the MEC2105 (Project 2) project develops teamwork abilities by extending to the implement and operate process steps. In the respect of contest rules, students in teams must design and build complete solutions and compete against all other teams at the end of the term. Responsibilities for relationships and project planning increase compared to the 1st year project. It is a good opportunity to verify how the students use the principles learned and the skills developed during the first year project and team work training course MEC1201 (Teamwork training).

The third year MEC3900 (Project 3) seeks to develop individual abilities and technical understanding of all project phases. At the third year level, the technical knowledge acquired in engineering disciplinary courses is sufficient to address technical issues in an industrial process including product design. The third year individual project goes through all the design process steps, analyzing and solving complex technical issues. Teamwork in this context becomes the interactions with industry professionals, the tutoring professor and the student in the day to day exchanges required during the product development process.

The fourth year integrates all acquired knowledge in a multi-disciplinary industrial sponsored project MEC4340 (Project 4, and similar specialty capstone project courses). Large multi-disciplinary project teams (20+) in the 4th year, validates all previous project-based learning outcomes, but this time in an industrial context. In order to match one of the fundamental practices of concurrent engineering typically deployed in industry, namely Integrated Project Teams (IPT), this project was developed in collaboration with three other academic institutions: Ecole Polytechnique (engineering), University of Montreal's School of Industrial Design and HEC Montreal (business and management). The open-ended project scope is supplied and supervised by an industrial partner who plays the role of customer and/or technical advisor over a two-term period. Milestones and budgets are established by the schools and the customer but team structures, project scope, timelines to meet milestones, etc. are defined solely by the students. Teaching staff from each school acts as mentors in the project team, but all actions taken need to be justified by the students.

A theoretical course, MEC4320 (Mechanical components analysis and optimization), is integrated in the capstone project. 3D finite elements, in-deep analysis and new optimization techniques are presented in the theoretical course. The application work in MEC4320 comes from the capstone project's product analysis needs. Students from the capstone project become team-leaders for the theoretical course students. The capstone student's organizational skills and team management abilities are called upon to successfully carry out the MEC4320 in-course applications. This in effect reproduces sub-contracted work that is then fully integrated as part of the design validation or optimization of the industrial capstone project product.

Myers-Briggs Type Indicator (MBTI) testing is done on all participating students. A competence and preference sheet (CPS) is also filled out by the students so team members know the strength and weaknesses of the team as a whole. Peer review evaluations [3] are done at each important project milestone. Professors use all this data to observe team structure choices and follow closely the teamwork dynamics evolution.

Over the 4 year curriculum, the project authority is transferred from the teaching staff to the student team members. The 4th year capstone project brings student to an almost complete autonomy of action in project decisions to answer the external customers expressed or latent needs.

Educational support tools and practices to foster teamwork experience

Myers-Briggs Type Indicator (MBTI)

At the onset of the 4th year in preparation for the capstone projects, the Myers-Briggs Type Indicator (MBTI) is used. It is a robust psychometric instrument measuring individuals' innate personality predispositions based on four dichotomous scales: energy, perception, judgment and orientation (Table 2).

Energy	
Extraversion (E)	Introversion (I)
Perception	
Sensation (S)	Intuition (N)
Judgement	
Thinking (T)	Feeling (F)
Orientation	
Judging (J)	Perception (P)

Table 2. MBTI dichotomous scales

From this classification, 16 personality types are derived each having distinct reactions and approaches to problem solving and decision-making. The population distribution of MBTI types in the adult USA population [4] is not uniform certain types being less frequent than others (Table 3).

ISTJ 11,65 %	ISFJ 13,75%	INFJ 1,45%	INTJ 2,05%
ISTP 5,45%	ISFP 8,75%	INFP 4,35%	INTP 3,3%
ESTP 4,3%	ESFP 8,5%	ENFP 8,05%	ENTP 3,2%
ESTJ 8,75%	ESFJ 12,2%	ENFJ 2,45%	ENTJ 1,8%

Type	%	Type	%
E	49,2	TJ	24,3
I	50,8	ST	30,15
S	73,3	SF	43,2
N	26,7	NF	16,3
T	40,5	NT	10,35
F	59,5		
J	54,1		
P	45,9		

Table 3. American National Representative Sample (1996)

The instrument can be used for personal understanding of differences in styles [4] (i.e. decision-making, leadership), team dynamics (strengths and weaknesses) as well as occupational trends [5]. The 4th year capstone project uses the MBTI data to understand, with hindsight, how team dynamics are linked to team member personality types.

Comparisons of engineering student populations [6] with normative samples [4] show an over-representation of sensing and thinking types (factual, objective analysis, practical and matter-of-fact) and an under-representation of intuitive and feeling types (imaginative, personal warmth, enthusiastic and insightful) [4, 7].

Part of this bias can come from the fact that in the general population, women are over-represented in the feeling types (75%) and men in the thinking types (56%). The small number of women in engineering faculties further increases the proportion of the thinking type in our schools.

We compiled the MBTI data from our last two capstone projects of 2006-07 and 2007-08 (Tables 4 and 5).

ISTJ 4 | 2	ISFJ 0 | 1	INFJ	INTJ 0 | 4
ISTP 0 | 2	ISFP	INFP	INTP 1 | 1
ESTP 2 | 0	ESFP	ENFP 1 | 0	ENTP 2 | 1
ESTJ 1 | 3	ESFJ	ENFJ 0 | 1	ENTJ

Table 4. Total students per type in 2006 and 2007 project teams

Preferences	2006 team %	2007 team %	USA Pop. %
E	54,6	33,3	49,2
I	**45,4**	**66,6**	**50,8**
S	63,6	53,3	73,3
N	26,4	46,7	26,7
T	**90,9**	**86,6**	**40,5**
F	9,1	13,4	59,5
J	**45,4**	**73,3**	**54,1**
P	54,6	26,7	45,9
Pairs			
TJ	**54,6**	**60**	**24,3**
ST	63,6	46,6	30,15
SF	0	6,6	43,2
NF	9,1	6,6	16,3
NT	27,27	40	10,35

Table 5. Type distribution for 2006 and 2007 project teams

At the onset of the 2006-07 capstone project, the teaching staff's initial assessment was that the student team had an apparent lack of depth of knowledge and poor (indecisive) leadership.
The team surprised the teachers by:

- finding the right process almost immediately
- focusing on consensus and
- finding solutions through concrete work.

The team had a preponderance of extraverts (action-oriented, breadth vs. learning through action and depth) dominant sensing types (pragmatic and factual as opposed to imaginative and theoretical, deeds rather than words) and perceivers (open-ended, flexible and adaptable). It is possible that the initial assessment was biased by the university's own bias towards introverted preferences, where careful analysis should precede actions.

For the just completed 2007-08 capstone project:

- team had a decisive leadership and did not depend on consensus building.
- personalities seemed to be more able to comprehend complex problems, have more technical knowledge justify demands and seek more independence in their work styles.
- roles and responsibilities as well as the work structure were redefined several times before arriving at the final, efficient one.
- 60% bias towards Thinking-Judging types is typically signs of tough-minded executives [8], with an inclination towards problem solving and implementing ideas.
- team had mainly introverts (depth of understanding).
- predominantly judging types (decisive, planned, and organized)

Furthermore a surprising 26% of the 2007-2008 team was of the INTJ type, compared to 2,1% found in the general population. This type is described as "original minds and great drive for their own ideas and purposes (…) skeptical, critical, independent, determined, stubborn". Often seen as brilliant but arrogant [9].

Competence and preference sheet (CPS)

At the beginning of the 1st and 4th year projects students must complete a self assessment Competence and Preference Sheet (CPS). The sheet is organized in 4 rubrics defining main competencies (Figure 1):

- A – interpersonal communication skills and leadership
- B – project management,
- C – technical knowledge
- D – hands-on and/or test-rig experience

Member profile evaluation Student code:........................

Class	Caracteristic	Appreciation	Remarks and justifications
Type preference	MBTI		
A HPR – Personal and relational abilities	Oral communication		
	Written communication (report writing, presentations, synthesis, etc)		
	Relational abilities		
	Leadership		
B Project management	Schedule planning		
	Task identification and allocation		
	Budget planning		
C abilities and technical knowledge	Static analysis		
	Dynamic analysis		
	Automotive mechanics (propulsion, suspension, etc, loads, chassis dynamics, etc)		
	Automotive electronics (propulsion, controls, wiring, etc)		
	Manufacturing (processes, machine-tools)		
	Materials (metalic, plastics, composites, etc)		
D Hands-on abilities	Experimental assembly (preparation, testing, results interpretation, etc)		

1. On a scale of 1 to 5 (1 – weak, 3 – average, 5 – excellent) indicate in "Appreciation" your estimation of performance.
2. Indicate the order of categories ABCD that represents best your preferences. (Ex : CDAB, ABCD, etc) : ………………………………………

Figure 1: Competence and Preference Sheet (CPS)

Every rubric is detailed in evaluation criteria to help students identify their strengths or weaknesses throughout their entire academic training. A comment column is added to further define previous experiences or interests. Finally a combination of letters (BCAD, ADBC or other) is used as shorthand for their preferred activities to be completed during the project. This choice demands self-reflection and communicates to the team an individual's perception of his ability to complete specific project tasks or roles. When structured team organization and responsibility assignments are to be defined, the student has already reflected on a preferred personal involvement area in the project. For example, during the 2006 and 2007 capstone projects, project managers presented in their competence and preference as ABCD and ABDC. In the "remarks and observations" column they both justified a strong ability and/or experience as a project leader justified by their academic or extra-academic activities.

In the MEC1110 1st year project the knowledge gleaned from Competence and Preference Sheet (CPS) is used to build teams that contain diverse types in order to generate rich team interactions.

The MBTI and CPS tools are voluntary. Students can choose not to complete the documents. The gathered information is not used to influence the student team's management, individual responsibilities, tasks or roles. Students have access to the information but use it rarely to sort out team issues or internal team dynamics. The insights provided by the MBTI and CPS tools helps the teaching staff better judge team dynamics situations in relation with who is part of the team. Never will the teaching staff impose team functional rules that could be incompatible with the predominant personality types in the team. Experience has shown us that teams can deliver good project results even if the teaching staff finds their internal team rules different and contrary to their own personal experience of what an effective team is.

Team dynamics evaluation

The teamwork training course MEC1201 brings students to identify and understand the different factors that affect interpersonal interactions and practice interpersonal communication abilities. We aim to help students:

- Identify the influence of their behavior on others and the effect of other's behavior on them;
- Adopt affirmative behaviors to promote their authenticity and effectiveness while communicating with others using active listening, feedback and managing conflict situations;
- Identify internal team standards and roles;
- Adopt behaviors that favor participation, decision making and team cohesion;
- Define change objectives to improve team dynamics and task management;
- Listening to, receiving and emit constructive criticism.

We chose to interpret team events using, among others the spiral evolutional model of small groups [10]. In this model day to day team activities are included in three dynamic zones defined by: affection, power and task (Table 6).

Affection	Represents the team's psychosocial state. We find in this zone the affective relations between team members and the emotions lived by each team member in response to what the team is experiencing (sympathy, frustration, calm, etc).
Power	Represents the implicit internal team structure that gives more power to specific individuals in the team. Leadership is supported by the recognition of a person's ability to support other team members' needs and aspirations.
Task	Observes team management, procedures and methods.

Table 6. Three zones of the spiral evolutional model of small groups

Students are trained and guided to retroactively analyze their own team dynamics using these criteria to better understand and correct ineffective team behaviors.

Internal team regulation
Effective teams have the capacity to auto-regulate themselves. One of the ways of doing this is to provide quality feedback to other team members. This feedback is specifically aimed to give information on how one person's actions affects other persons. By this return of information on his words or actions the person can then reconsider his behavior and eventually change or repeat his future actions.

Feedback must not become an opportunity of accusing colleagues for what they are but to question specific actions and behaviors. Students learn to give descriptive (based on facts) or experiential (base on self) feedback. This feedback can be positive or critical [11] (Table 7).

Positive	Puts forward all actions and words and recognizes explicitly the behaviors, attitudes or performance that contributes directly or indirectly to achieve project objectives. Positive feedback serves to reinforce a desirable and effective behavior.
Critical	Critical feedback approaches the limit of confrontation. Confrontation aims to critical thinking, alternative solutions, expansion of possibilities, questioning work practices. Critical feedback is necessary to modify ineffective or inappropriate behavior, inadequate performance or to rethink unproductive processes.
Descriptive	Addresses only the observable and verifiable. Description of behaviors, events, situations or observed results.
Experiential	Description of personal reactions, sentiments or emotions of the person giving the feedback. Naming the affective reaction linked to our experience constitutes the experiential dimension of feedback.

Table 7. Proposed feedback types for team dynamics reviews

The teamwork abilities developed through these tools and training aim to diversify student's strategies to achieve their goals. Individual mindsets transform from “me” to “us” through effective team dynamics.

Lessons learned from the observation of student team dynamics
The presented methods help students and the teaching staff to better observe and reflect on team functions and dynamics. However, they do not provide any indication how to evaluate team performance. How do we measure and rate effective team learning dynamics through project performance and output quality? How do we reward individual efforts, team performance and quality of output in an academic environment? These aspects are addressed by combining evaluation methods that together can reflect the complexity of team performance. The detailed evaluation methods are described in a separate presentation at this CDIO conference [3].

The tailoring of teams to ensure opinion diversity creates an interesting side effect. We observed the diverse profiles of the multi-disciplinary capstone teams created openness for what Tom

Kelley of the product design firm IDEO calls "T shaped individuals" [12]. T-shaped people have a strong main disciplinary knowledge (engineering or design knowledge) but also a wide view of other disciplines and their required collaboration in effective project work. The collaboration between engineering, industrial design and business students on a common product creates a wider view of product requirements than the sum of the three isolated groups.

At the start of all 4th year capstone projects we invite past project leaders to present to new project teams. Our experience shows that new students do not understand the value of the warnings and information they receive even though they will be confronted to the same issues during their project. Furthermore the reflex of going back to this presentation is absent and solutions always come from rebuilding from scratch instead of learning from past mistakes. We found that linking future project activities to past personal project experiences generates the best reaction from students. Having projects in every year multiplies the possible experiences and therefore produces more anchor points for the teaching staff to generate pro-active actions from students.

Future developments

We find personality type consciousness (MBTI and CPS) needs to be started earlier in the curriculum so students can mature more on interpersonal issues before the 4th year project course. Plans are being developed to introduce the Myers-Briggs Type Indicator (MBTI) in the first year MEC1201 Teamwork course. This early introduction will permit a longer period to assimilate the effects of personalities in the MEC1110, MEC2105 and following project courses by students. It will also be possible to look at the evolution of the CPS and MBTI data over the 4 year curriculum and see how better understanding by students of personality differences can improve team dynamics.

Efforts are required to increase in the next few years the number of students involved in the 4th year capstone projects. Presently 20 engineering students follow the MEC4340 multi-disciplinary project course. September 2008 will see the experience scaled to 120 students in similar disciplinary projects (Aeronautics, Mechatronics, Design and Manufacturing, etc.). Questions surrounding scalability of the project experience, project space allocation and controlling teaching staff support costs will be validated based on our deployment plans.

Scaling the experience to delocalized locations is also being evaluated. We would like students to experience the effect of cultural differences in teamwork through multi-site collaboration between teams in different countries.

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Danielle Poirier has led teambuilding interventions with executive teams across many fields for thirty years. As faculty member of the international Association for Psychological Type, she is responsible for qualifying professionals in the use of the Myers-Briggs Type Indicator. She authored THE MAGNIFICENT 16, a multimedia software program that illustrates the different personality types and as well as the challenges that teams face with psychological diversity.