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Impact of Team Functions in an Introductory Design Course on Student Performance in Later Design Courses: A Longitudinal Study*

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In ME Tools, an introductory undergraduate mechanical engineering course, students work in teams, acquiring design and process development knowledge. Throughout the course, each student assumes one of four possible roles: manager, systems engineer, analyst, or details designer. Team function assignments are based on student response to a short questionnaire. This paper reports on the findings of a longitudinal study that tracked the performance of 204 students as they progressed through the design curriculum up to and including the final year project course. Tracking is achieved using repeated measures ANOVA (RMANOVA). Interactions between the introductory course grades and sub-grades of the major deliverables (report and contest) and those from the other design courses were statistically examined after being divided according to team function. The strengths of these interactions (p values) are reported, with the impact of team functions on performance in the design courses taken by the students often being shown up to three years later in their curriculum. It was also found that 64% of all teams formed for the capstone project contained two or more members of the team originally formed in ME Tools.

Keywords: mechanical engineering; design; process development

1. Introduction

Engineering courses that subscribe to the active learning methodology emphasize experimentation in the early years through practical shop and lab exercises [1]. In active learning methods [2], students are actively involved in the learning process, in contrast to the passive listening role traditionally taken by students. Similarly, collaborative (as opposed to individual) learning and cooperative (as opposed to competitive) learning methods have gained substantial recognition in curricula development. Collaborative learning methods (e.g. [3]) mainly propose that students work in small groups working toward accomplishing a common goal. In a closely related method, cooperative learning (e.g., [4]) proposes that students work in teams but are individually assessed. It incorporates five principal practices for it to work properly: individual accountability, mutual interdependence, face-to-face interaction, appropriate use of interpersonal skills, and self-assessment of team functioning. While the students direct their own learning, the problem-based approach to learning involves the tackling and solving of open ended problems (e.g., see [5]).

The intra-dependence of team functions provides students with the accountability that they would demonstrate through individual-based assessment and should contribute to an environment conducive to learning in teams. A survey of the literature testifies to the fact that understanding, assessing, and enhancing team performance in general [6], and student teams in particular [7–9], is of great interest. Specific to engineering student design teams, recent examples include the work by Keefe *et al.* [10] who assessed student team performance involved in engineering design projects. Furthermore, team dynamics as relates to team performance was addressed by Gale and Knecht [11] who examined undergraduate team performance and functions by focusing on behaviors aimed at a team-centered approach to problem solving. Lingard and Berry [12] addressed the effective team functioning of software engineering students. In order to add technical depth in undergraduate design education, Manuel *et al.* [13] used graduate students as coaches. Lewis *et al.* [14] studied team skills acquisition via team experiences that promote good team processes and self reflection. Williams *et al.* [15] used peer evaluation to improve team performance. Terpenny *et al.* [16] used assistive technology design projects and interdisciplinary teams to foster learning in engineering design. Delson [17] studied the effect of team motivation in capstone engineering courses and found that it can significantly affect the quality of the project outcome. More recently, Fernndez *et*

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al. [18] presented a study of behavioral variables implied in the working dynamics of student groups undertaking their first project. Trevelyan [19] stressed that coordination in engineering projects is an informal process. He is unaware of any engineering course that has a formal development of project coordination skills but proposes that an engineering education should provide opportunities for students to develop effective coordination skills.

Interest in classes that teach product development based around problem-based learning has flourished [20–22] with many of these classes adopting team formats [23, 24]. At the American University of Beirut (AUB), MECH 321 Mechanical Engineering Tools (ME Tools, as it is called [25]) is an introductory design and process development course for mechanical engineering students. It is offered to students in the first semester of the second year of the engineering program (a five-year program fitted into four calendar years, including three mandatory summers). Naturally, conducting such a course in a higher education setting is best accomplished via active learning methods. The course is structured to integrate the best practices of active, problem-based, collaborative, and cooperative learning methods. As students practice first-hand the design process methodology, they are introduced to several design 'tools of the trade', encompassing both software-based tools (e.g., MATLAB, CAD/CAM, and project planning) and hardware-based tools (e.g. reverse engineering, assembly, and fabrication). Activities and deliverables, organized to accomplish pre-specified rubrics, are based on a central theme: the designing and building of an electric micro-car to compete in an end-of-term contest. Students work in multifunctional teams organized along four team functions: manager, systems engineer, analyst, and details designer. Rubrics are used as the basis for assessing the students' performance. However, although the fulfillment of the course learning outcomes entails design and process development knowledge, the student's function on the team to a great extent determines the specific type of knowledge acquired: management, systems engineering, analysis, or detailed design.

The longevity of course learning outcomes is of great interest in engineering education. For example, Felder *et al.* [26] used longitudinal studies for tracking student performance (based on the grades earned) in a series of five consecutive active and cooperative learning courses. Others [27–29] used longitudinal studies to study educational issues related to gender and minorities. Cobb *et al.* [30] reported on a longitudinal study of learning outcomes in a new product development class that practices learning design 'tools' while working in multifunctional teams. Demel [31] used a longitudinal study to evaluate an honors program for freshman engineering students.

Since the format and organization of ME Tools requires students to perform tasks along one of four functions, the need to assess the long-range effects of these functions is the primary issue in this research. The primary hypothesis is that the team function experience acquired by students, along with the closely-practiced team tasks, will have a significant impact on student (grade) performance in later design courses. To that end, this paper aims to answer these research questions:

I.1. Can student performance in ME Tools, having practiced a host of design and process development skills in a collaborative environment, be correlated to student performance in design courses taken later in the program?

I.2. Does the team function performed by the student (and the specific type of knowledge practiced) influence the students' performance in design courses taken later in the program?

The paper goes about answering these questions in a systematic way as follows. In Section 2 we briefly describe the course administration, outcomes, and example deliverables (see [25] for more details). In Section 3, we explain team functions and the team forming procedure. Section 4 describes the deliverables-based course assessment. Section 5 illustrates the open problem-based 'Gee Whiz Micro-car' contest. Section 6 explains the methods used. Section 7 reports the statistical results of the longitudinal study. Section 8 is a discussion section. The paper concludes with Section 9, which contains the lessons learned and recommendations.

2. Course description and administration

The introductory course emphasizes product and process development. The students take on an open-ended engineering problem, namely to design and build a custom, electric micro-car. ME Tools' setting, administration, and content are all designed to walk the students through one semester of emulated product development cycle spanning from the early stage of a specification in week 1 all the way to a product delivery (contest) in week 15. Starting from a statement explaining the contest, student teams start by identifying functional requirements and then devising practical solutions (design parameters) to satisfy those needs. Working from a common kit, the students (1) design, (2) fabricate, (3) integrate, and (4) test the micro-car (engineered product). Having constructed their little cars, the students race their creations in a five-event contest known around the AUB campus as the 'Gee Whiz Micro-Car Contest'. The primary premise of the collaborative learning of working in small groups while focused on one goal is met via the delivery of the micro-car.

The relevant topics are introduced in an integrated, systematic, and orderly sequence while being performed in a student-centered, project-based manner. This is accomplished via three-parallel tracks of weekly activities: lecture, lab, and supervised team meetings. All 15 lecture topics and the parallel 15 lab/shop sessions are designed accordingly, dealing with diverse topics. The large-class, 75-minute lectures held on Monday morning sets the tone for the topic covered during the week. While some lectures emphasize 'hard' topics (such as an introduction to mechanical design, product design methodology, elements of engineering drawing, control and instrumentation, mechanical power and transmission, 3D CAD, material selection, and fabrication and assembly techniques), others cover 'soft' topics, including the principles of team work and professional ethics, identifying requirements, scheduling, economic considerations, decision making, product architecture and system configuration, and creativity and innovation. Guest lectures are invited from the faculty representing various disciplines, and professionals from the industry and engineering alumni chapter. Pre- and post-lecture tasks are regularly assigned.

Lectures are followed by laboratory sessions of 3 hours/week (with 20 students per session maximum capacity). Students meet mostly in the special projects lab, where the first 30 minutes involve an orientation lecture about the lab work. Each student is required to log all laboratory activities using a lab journal. Lab activities are closely coupled to the topic of the week and, in addition to lab activities, pre- and post lab activities are also included. The software tools tackled in the lab include: MS Project®, 3D CAD pro/Engineer (used to build complete models of the micro-car), MATLAB® (e.g., used for micro-car design and optimization), Mindstorms Lego® (control software), and MS Excel. Hardware tools include Mindstorms Lego® robot kit assembly and operation, motors, PCB construction (routing, stuffing, and soldering of electronic components), mechanical characterization (friction coefficient and dynamometer), and metal work, fabrication, and assembly.

Supervised team meetings involve the students in each team separately under the supervision of a graduate assistant. Coordination issues related to the design and fabrication of the project are discussed and progress monitored against the master project schedule. Performance of the team members is assessed and this evaluation becomes part of the course grade.

In practicing with the newly-learned tools, students produce many deliverables in a timely fashion to help them meet their project milestones, including: Pugh matrices for evaluating alternate designs, force analyses and free body diagrams, elementary motion kinematics, characteristic curve of the drive motor, shear and deformation diagrams of the shaft in the drive train, and solid CAD models of their micro-cars.

The course is coordinated by one full-time faculty member who is in charge of the lectures and is responsible for coordinating lab sections, while labs are run by instructors and graduate assistants. All lectures, lab material, assignments and assessment reports are posted to students through Moodle®.

3. Team functions and composition

The students work to incorporate the micro-car requirements provided by the instructor into a finished product. They do so while going through the entire cycle of product development in a way that mirrors that of industrial settings, including the phases of: devising a product specification, engineering analysis, detailed design, and fabrication, as well as integration and assembly. The students work in monitored teams of four divided into four functions: manager, systems engineer, engineering analyst, and details designer as follows:

- *Function I* The manager or 'the Big Wig': forms the problem statement, does the scheduling and planning, manages manpower, conducts literature survey, and is responsible for overall report documentation.
- *Function II* The systems engineer or 'the Big Picture': bears primary responsibility for devising the contest winning strategy. This function defines the design parameters and translates requirements into engineering specification, prepare product configuration, identify potential scenarios, and makes the car's hand sketches.
- *Function III* The analyst or 'The Brains': is responsible for the engineering and mathematical solutions, and develops, among other things, the basic free body diagrams.
- *Function IV* The details designer or 'CAD guru': responsible for developing detailed designs using 3D CAD and producing the detailed parts list.

Team forming involves two challenges. The first

1. In meetings, I generally tend to
   A. sit back and observe
   B. make my opinions known
5. My friends and I are to perform an experiment and to write a lab report, given the choice, I'd rather
   A. do the technical work
   B. write the report once my friends finish doing the work
9. When I play sports, I generally tend to
   A. play a specific position
   B. be the team's captain
13. Immediately after graduating with an engineering diploma, I believe I would want to
   A. work as a practicing engineer
   B. move into management by attending business school
17. If I were to be a honey bee, I think I would be
   A. a soldier bee
   B. the queen bee

Fig. 1. Questions for choosing 'managers'.

2. When working on re-assembling my auto engine, I find myself
   A. studying the manual at length before I start
   B. going to it with the tools
6. I feel that plans, procedures and guidelines are
   A. critical to the success, or failure, of a project
   B. waste of time
10. I believe that in a machine the
   A. overall layout and how it functions is more important than the sum of its parts
   B. the detail and quality of its individual components is more important than the overall layout
14. In the car that I drive,
   A. I have a pretty good idea how the major parts and components connect into each other to make the car run
   B. I don't have the slightest idea how the major parts and components connect into each other to make the car run
18. While telling a story or explaining an idea, I tend to focus on the overall picture and do not try to sweat out the details
   A. Yes
   B. No

Fig. 2. Questions for choosing 'system engineers'.

3. My friends and I are performing an experiment, given the choice, I'd rather
   A. perform the experiment
   B. analyze the results
7. I am given a difficult equation to solve. I find myself more often running for
   A. my friend, Mr. Brains
   B. the calculator
11. I find myself able to comprehend mathematical symbols and functions
   A. with difficulty
   B. without much effort
15. When I think of projectile motion, immediately comes to my mind
   A. the idea of a rocket ship going to Mars
   B. the acceleration-velocity-distance formulae that I learned in high school physics
19. In the car that I drive
   A. I don't have the slightest idea how the gasoline engine generates mechanical power
   B. I have a pretty good idea how the gasoline engine generates mechanical power

Fig. 3. Questions for choosing the 'analysts'.

4. Before I buy a new bike, I find myself wanting to first
   A. inspect and admire the quality of the componentry
   B. take it for a spin around the block
8. When my car breaks down, I, more often
   A. roll up my sleeves and try to fix it
   B. get it fixed at the neighborhood's mechanic
12. In order to capture an image, I prefer to
   A. hand sketch it
   B. take a photograph of it
16. If I run across a complicated engineering drawing, I find myself
   A. trying to de-cipher its code (layouts, dimensions, notes, etc..)
   B. running for the exit door
20. When I look at an interesting piece of art, e.g. painting, I
   A. try to examine the details (style, color, brush stroke, etc.)
   B. admire it and move on

Fig. 4. Questions for choosing 'details designers'.

is to match individual students to suitable team functions. Once done, the other challenge becomes team composition: Do students pick their own teammates or are team members assigned at random? During the first year that ME Tools was introduced, team function assignments were made based solely on the students' resumes that they had submitted at the start of the semester. In them students had been asked to identify their 1st and 2nd preferences. Instructors then assigned the students to the different functions based on these preferences and other information contained in the students' resumes. More recently, a method was developed for identifying student functional preferences based on their response to a 20-question questionnaire. Each function is targeted by a set of five focused questions dispersed throughout the questionnaire. Questions 1, 5, 9, 13, 17; questions 2, 6, 10, 14, 18; questions 3, 7, 11, 15, 19; and questions 4, 8, 12, 16, 20 correspond to the functions of manager, systems engineer, analyst, and details designer, respectively. These questions are shown in Figs 1–4. The highlighted answers reveal the most applicable response for the function of interest. Only two responses 'A' and 'B' are allowed for each question.

For each student, the responses are tallied and totaled based on the difference between the 'A' and 'B' responses. The number of 'correct' responses determines the strength of the function preference (on a scale of 1–5). The higher the score, the stronger is the preference for the function. For example, a student with four B and one A response to any set of five questions in any one of the functions has a net response of 3B. Table 1 lists four examples of actual responses. The first row represents a student with five A responses to the questions in Fig. 4, indicating a very strong tendency for performing detailed tasks. The actual function that is assigned is based on tallying the scores as shown in the last two columns. Performing this methodically results in segregating the students along the four functions. Regarding team composition, once the function profile of individual students is determined, the students are randomly assigned to their respective teams (provided these students belong to the same section

Table 1. Scoring of four actual examples of questionnaire responses

	B		A		B		A		
No.	**Manager**		**Systems**		**Brains**		**CAD**		**Assigned function**
1	3A – B = 1A	1A	4A – 1B = 3A	3A	3B – 2A = 1B	1B	5A	5A	CAD Guru
2	3A – 2B = 1A	1A	4A – 1B = 3A	3A	4B – 1A = 3B	3B	3B – 2A = 1B	1B	Brains
3	4B – 1A = 3B	3B	3A – 2B = 1A	1A	3B – 2A = 1B	1B	3A – 2B = 1A	1A	Manager
4	3B – 2A = 1B	1B	5A	5A	3B – 2A = 1B	1B	3A – 2B = 1A	1A	Systems

of 20 students). The intent is to mimic industrial occupational settings where an engineer does not usually choose his or her project teammates.

4. Course assessment

For assessing student performance, delivery platforms such as presentation, reports, and contests are required. The deliverables are linked to ME Tool's learning outcomes and, consequently, grades are assigned using a grading rubric. Rubrics focus on communication skills, technical knowledge and documentation, and concept synthesis. Scores for the various criteria in the rubric are added to arrive at a deliverable total report grade. An example of a rubric used in grading the report is provided in the Appendix.

Graded platforms contain a combination of milestones, some of which are achieved individually while others are submitted as a team. Specifically, these assessment components are:

1. Lecture Assignments (5%; Team deliverable).
2. Lab/Shop Milestone Assignments (15%; Mixed individual / team).
3. Attendance (5%; Individual).
4. Project Notebook (5%; Individual but based on student's team function).
5. End-of-Term Team Presentation (5%; Team).
6. Final Design Report (20%; Individual but based on student's team function): major document delivered at the end of the term. The report assessment criteria for each team function are laid out according to strict rules with assessment components mapping precisely to each function's primary responsibilities. Each category is given a corresponding symbol (e.g., M1–M5 for managers) for identification and is given a percentage of the report grade. See Appendix.
7. End-of-Term Contest (25%; Team).
8. Final Exam (20%; Individual).

5. The gee-whiz micro-car contest

The micro-car design is open ended with multiple potential feasible solutions given the generic nature of the requirements of the five events that constitute the contest:

- *Event 1* Speed demon: From rest, cars sprint 30 m distance without going out of bounds (3-m wide lane).
- *Event 2* Traction and stability: Starting from rest, cars will climb a 2-m long, rubber-coated ramp (45° incline) without tipping over.
- *Event 3* Obstacles course: Starting from rest, cars will crawl over sand, gravel, and a handful of obstacles and half pipe sections.
- *Event 4* Tug-of-war: Starting from rest, cars will eliminate each other by pulling each other a predefined distance.
- *Event 5* Evel Knievel: Starting from rest, cars accelerate and propel off a ramp.

Contest requirements are diverse as evidenced by the simple, yet demanding, requirements for each event including the requirement that all cars should use a 'common kit'. In order to allow for design creativity, this kit contains only a DC electric motor, a control PCB (fabricated by the students in the controls lab session), and a 12-volt rechargeable battery. All other components are either bought or made (including the drive shaft). No restrictions are imposed on hardware selection or use, car size/weight, etc.

6. Methods

In order to address the two research questions (I.1–I.2) posed above, proper methods must be implemented, which involves, respectively:

- VI.1. Determining a suitable outcome for measuring a student's interaction with later courses (grades, sub-grades, statistical measure such as p values, etc.). It was initially attempted to use course grade and sub-course assessment scores to answer this question by tracking individual students through two classical design courses and a design capstone course taken later in their studies. As will be explained below, it was found that the grades did not differ much across the various functions, rendering the grades unusable of themselves. However, significant differences were found when examining statistical interactions (as indicated by p values) making this statistical measure a natural choice in this study. Since measurements correspond to the

Table 2. Mean and standard deviation of ME Tools sub-grades (segregated by ME Tools team functions)

	ME Tools average subgrade: by function				
	Report	**Contest**	**F. Grade**		
Mean (s.d.)	79.0 (17.1)	87.6 (12.3)	77.4 (7.0)	Manager	n = 53
Mean (s.d.)	74.3 (20.7)	88.2 (11.8)	77.4 (8.4)	System	n = 49
Mean (s.d.)	76.7 (19.1)	86.2 (12.2)	75.6 (13.9)	Analyst	n = 54
Mean (s.d.)	84 (15.9)	87.4 (12.5)	78.9 (8.2)	Designer	n = 48

same subjects but are recorded at different times, one-way repeated measures ANOVA (RMANOVA) was used.

- VI.2. Using the measure determined in VI.1, identify key function-specific ME Tools deliverables of sufficient quality, and caliber (% of course grade) to be measured. Performance is assessed in terms of the strength of statistical interactions between the student course score vs. the score attained on function-specific deliverables (e.g., report) and team-based group deliverables (e.g., contest). However, in order to isolate the function-related issues from other dynamic issues, a control group would have been used for comparison. Unfortunately, no control group was possible in this study, given that ME Tools is a required course and that this was a longitudinal study over many years with repeated measurements, which makes such a control group prohibitive. The obvious downside to not having a control group is that variables such as maturity, the impact of experience, and improved study habits that are gained through the curriculum cannot be distinguished from the impact of the introductory course.

Three consecutive cohorts of ME Tools students were tracked over three years. In total, data were collected over six years. Of 236 ME Tools students, complete data were available for only 204 students at the conclusion of the study due to attrition and other administrative issues. The breakdown according to team functions was: 53 managers, 49 systems engineers, 54 analysts, and 48 details designers. These students were 19–20 years old, the great majority of whom were of Lebanese descent, entered the ME program with fairly similar SAT and high school scores, and were almost all male (except for 14 females, or 7%). Owing to their relatively similar technical backgrounds, it was assumed that the most noteworthy difference among the students in this study is the team function itself. Also, given their inexperience, it was assumed that students enter this course with practically no mechanical design experience and that the skills learned could be attributed solely to the introductory course. While, in principle, all team members practice all aspects of the product development process, specific team members take responsibility for different aspects of the process. Mechanical design knowledge and design process knowledge are taken as having been learned by all students but not to the same level.

7. Longitudinal impact of team functions

The study tracked the performance of ME Tools students by recording their grades in ME Tools and in two traditional design courses, MECH 420 Mechanical Design I and MECH 520 Mechanical Design II. These two design courses are worth 3 credits each and are typically taken in the third and fourth years, respectively. In both of these courses, team projects are assigned where students design a mechanical system and present a summary report. Also tracked were the students' performances in the capstone design project, MECH 502 Final Year Project, a compulsory 5-credit course that contains a substantial design component and is taken in the last semester.

To help distinguish the impact (as measured by statistical interaction) of ME Tools on design classes, the students' performance in two other unrelated 'non-design' mechanical technical courses was also tracked. One course is MECH 340 Engineering Materials, which is typically taken one term after ME Tools. Another course is MECH 421 Manufacturing Processes, which is typically taken one term after MECH420.

7.1 Immediate impact: Second year

To determine the measure that satisfies requirement VI.1, the grades themselves were first examined. In Table 2, the performance in MECH 321 is dissected based on the grades of two major deliverables: the report (mixed individual/team deliverable) and the contest (team deliverable). Also listed as another indicator are the final course grades. Grades are segregated by team function (as noted above, the number of students varies). Table 2 reveals that mean deliverable scores as well as the course score show no significant differences amongst the four functions. Therefore, the scores themselves do not represent a useful measure for the study. On the other hand, as Table 3 shows,

Table 3. Interaction of ME Tools course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	ME Tools course grade vs. ME Tools subgrade: by function				
	Report	**Contest**	**F. Grade**		
p =	0.0001	0.0001	1.00	Manager	n = 53
p =	0.0001	0.0001	1.00	System	n = 49
p =	0.0001	0.0001	1.00	Analyst	n = 54
p =	0.0001	0.0010	1.00	Designer	n = 48

Table 4. Interaction of MECH 340 course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	MECH 340 Engineering Materials course grade vs. ME Tools subgrade: by function				
	Report	**Contest**	**F. Grade**		
p =	0.0977	0.2105	0.0062	Manager	n = 53
p =	0.1652	0.0058	0.0026	System	n = 49
p =	0.0381	0.4893	0.0075	Analyst	n = 54
p =	0.0738	0.6712	0.0223	Designer	n = 48

Table 5. Interaction of MECH 420 course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	MECH 420 Design I course grade vs. ME Tools subgrade: by function				
	Report	**Contest**	**F. Grade**		
p =	0.0049	0.043	0.0086	Manager	n = 53
p =	0.0043	0.0044	0.0086	System	n = 49
p =	0.0146	0.0576	0.0066	Analyst	n = 54
p =	0.0037	0.276	0.0004	Designer	n = 48

Table 6. Interaction of MECH 421 course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	MECH 421 Manufacturing Processes course grade vs. ME Tools subgrade: by function				
	Report	**Contest**	**F. Grade**		
p =	0.078	0.187	0.006	Manager	n = 53
p =	0.202	0.0519	0.0061	System	n = 49
p =	0.07	0.2867	0.2339	Analyst	n = 54
p =	0.0551	0.3248	0.0085	Designer	n = 48

significant differences were found when examining statistical interactions (as indicated by p values using ProStat [32]), among the various grades using RMANOVA. As one would expect, all of the grades show an extremely strong interaction with the ME Tools course grade with the report and contest grades exhibiting extremely significant interactions ($p < 0.0001$ for all functions).

For comparison, Table 4 lists the same statistics as in Table 3 but instead uses the course grade for the 'non-design' course MECH 340 Engineering Materials. Except for the final course grade, which shows strong interactions for all functions, the sub-grades show significantly weaker interactions than those in Table 3.

7.2 Impact one year later: Third year

When the cohort of 204 students is segregated by function as in Table 5 and examined as such, interactions are found to exist not only between the MECH420 final grade and that of ME Tools' but also more significantly with team function. Given that the report deliverable is graded individually based on the individual's function in the team, all four functions report scores that correlate well with their later MECH420 grades. Managers, being responsible of the overall structure and organization of the final report, correlate especially well (p = 0.0049). Also, system engineers, analysts, and designers documented their own contributions in a way that earned them grades that were consistent with their capabilities, leading to good interactions with their future performance in MECH420 (p = 0.0043; p = 0.0146; and p= 0.0037 for these functions, respectively).

Table 5 shows that system engineers students exhibit significant interactions between contest scores and their performance in the MECH420 design course (p = 0.0044) that far exceeds the interactions for all the other functions. By compar-

Table 7. Interaction of MECH 520 course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	MECH 521 Design II vs. ME Tools: by function				
	Report	**Contest**	**F. Grade**		
p =	0.274	0.157	0.0186	Manager	n = 53
p =	0.241	0.09	0.0348	System	n = 49
p =	0.0573	0.248	0.0377	Analyst	n = 54
p =	0.159	0.739	0.082	Designer	n = 48

Table 8. Interaction of MECH 502 course grade with ME Tools sub-grades (segregated by ME Tools team functions)

	MECH 502 FYP course grade vs. ME Tools subgrade: by function				
	Report	**Contest**	**F. Grade**		
p =	0.3388	0.11	0.0051	Manager	n = 53
p =	0.274	0.0013	0.107	System	n = 49
p =	0.216	0.064	0.198	Analyst	n = 54
p =	0.0263	0.602	0.0274	Designer	n = 48

ison, the contest also correlates for managers, but to a lesser extent (p = 0.043). Analysts and designers exhibited the greatest degradation in interaction from the year before (weak interaction of p = 0.0576 for analysts and no statistical interaction for designers, respectively). Instead of focusing on the contest itself, the 'brainy' analysts and their detail-oriented designer cohorts seem to have fallen back on what they seem to do best: scoring characteristically well on exams: (p = 0.0173 and p = 0.021, respectively; not shown in Table 5).

For comparison with Table 5, Table 6 lists the interaction values for the 'non-design' MECH 421 Manufacturing Processes course. Except for the course grade, most sub-grades show significantly weaker interactions than those exhibited with the design course MECH420.

7.3 Impact two years later: Fourth year

Table 7 is a snapshot in time 2 years after ME Tools when students take the second classical design course MECH520 Mechanical Design II. The table reveals that while a few interactions were found to carry over to year 4, many more have practically faded away. Even for the course-defining contest, systems students shows anemic (p = 0.09) retained interaction compared with that of this function's strong performance the years before.

7.4 Impact at graduation: Fifth year

The third and last monitoring point was the MECH502 Final Year Project. Many of this course's major deliverables resemble those of ME Tools: presentation, a heavy design project, and a final report. Although students work in teams (typically 3–4), they are free to select their teammates and are not required to function along the 'hard' functions implemented in ME Tools. Teammates in MECH502 may not necessarily earn the same grade since assessment allows some variation based on individual performance. Contrasting with Table 7, Table 8 shows a strong interaction that 'pops up' (p = 0.0013), corresponding to the system function's contest deliverable with the MECH502 grade. Other marked interactions include the report interaction for designers (p = 0.0263).

7.5 Impact of team membership

Another finding relates to the longevity of the composition of the team. Of the 51 teams formed in ME Tools over three different classes in three years, a remarkable percentage seems to have 'stuck it out' throughout the program. Although only one team fully regrouped for their final design effort in MECH502, 13 of the teams contained three of the original teammates and 19 teams contained two of the original teammates for a total of 64% of the original teams who retained two or more team members.

8. Discussion

The p values in Tables 3, 5, 7, and 8 are graphically displayed (plotted on a log scale) in Figs 5, 6, and 7 vs. the year in which assessment took place. The courses MECH 321, MECH 420, MECH 520, and MECH 502 are plotted at years 2, 3, 4, and 5, respectively. (Recall that the program is a five-year program fitted into four calendar years including three mandatory summers.) The figures represent the interactions, segregated by function, for report grades, contest grades, and course grades, respectively.

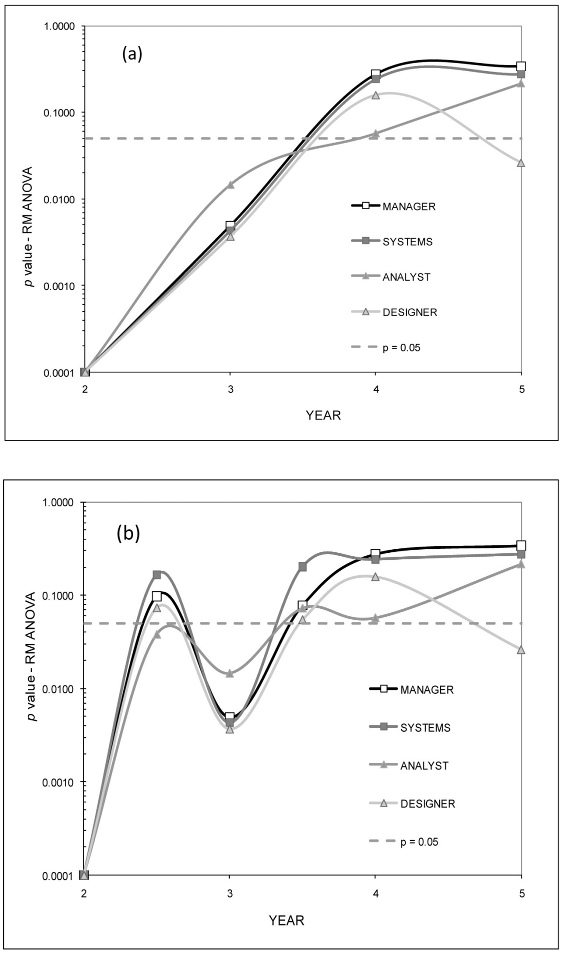

Fig. 5. (a) Impact trends for ME Tools' report grade. (b) Impact trends for ME Tools' report grade after the introduction of 'non-design' courses.

8.1 Report

The interactions of the report deliverable are examined in Fig. 5(a), which warrants the following remarks

- The strength of interactions is almost identical for all functions (is slightly off for analysts).
- The strength of interactions 'degrade' at a fairly constant rate with time.

These findings indicate that the ME Tools report deliverable may serve as a bellwether of how consistent the functions have been in navigating students through design skills acquisition in later design courses. The consistency is mostly preserved through year 3, despite the fact that the strength of the statistical significance wanes ($p \approx 0.004$). Although functions track beyond that year, the interaction strength decays for understandable reasons that reflect the dynamic nature of learning over time including maturing design skills as students gain knowledge beyond those initially acquired in the introductory course. The fact that the interactions are comparable for most of the functions reflects the importance of designing the assessment criteria as the assessment components precisely map to the function's primary responsibilities for each function (Appendix). This made it easier for assessors to mark the reports in a way that tells of 'who is hot' and 'who is not' at this early stage of the students engineering education.

To check the effect of 'design' vs. 'non design' courses, the p-values (Tables 4 and 6) for the two 'non-design' courses are introduced to Fig. 5(a) resulting in Fig. 5(b). The figure displays 'bumps' resulting from the introduction of these courses and causing major deviations from the clean trends established by the 'design' courses, suggesting that team functions interactions is not as significant for these 'non-design' courses as they are with the 'design courses' of interest. This lends credence to the idea that like-courses influence each other's outcomes and that interaction with unrelated 'non-design' mechanical technical courses may be ignored as inconsequential.

8.2 Contest

Figure 6 shows the strongest interaction over the duration with the contest grade for the system engineers, implying that the students taking on this function appear to have acknowledged the overall contest strategy. Their very high interaction even at the late FYP assessment ($p = 0.001$) is a testament to their statistically significant consistent performance. These 'system engineering' students seem to have kept up their strong leanings towards hands-on design skills and creativity. They appear to have learned enough (or not learned enough for the weak performers) from the contest learning experience to be 'set' (to borrow from the polymer reaction kinetics lingo) in their performance over the long haul. Therefore, a systems' student with low (high) contest grade in ME Tools is likely to earn a low (high) grade in later design courses (especially in a design-heavy course such as MECH 502).

Student managers and analysts show the same trends as those of the system's but with weaker correlations resulting in a 'medium' consistency by virtue of their mediocre p values as they went through the curriculum. Over time this caused something of a 'late gelling' effect. Analysts showed the second highest correlation retention of their contest experience (fairly flat and weak correlation; $p \approx 0.1$). The analysis rule assumed by the 'Analysts' appears to have some contribution to design skills. One explanation is that those 'book warm' students appear to have assumed a 'hands-off' attitude when it came to actually designing the micro-car. Below, it will be seen

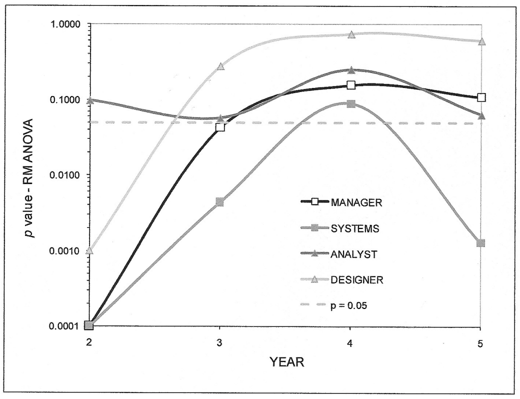

Fig. 6. Impact trends for ME Tools' contest grade.

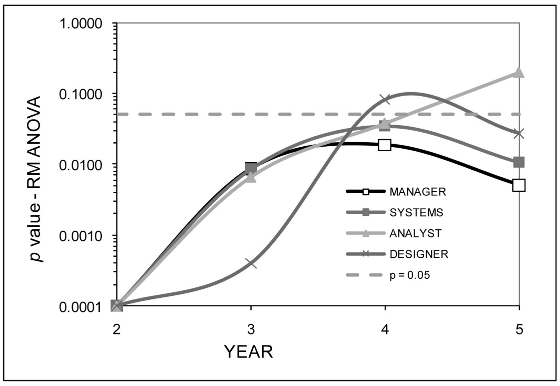

Fig. 7. Impact trends for ME Tools' course grade.

that these brainy students contributed to the contest' 'paper' design mostly through analyses and less by a 'hands-on' design but managed to demonstrate enough impact on their design efforts three years later. Another explanation may be that these students constantly reinvented themselves in design projects resulting in a true mixing of the scores of these students. Strongly acquired design skills in ME Tools appear to come in handy given the design opportunity presented in the design project in MECH502 FYP. This is another vindication of the relevance of design knowledge acquired in such an innovative design course.

After ME Tools, the designers' utter lack of correlation became evident. These students appear to be in constant turmoil regarding their future scores and lack of consistent performance in later design courses. The designers, however, seem to have 'gone along for the ride' without much to gain from the learning experience associated with the contest. They turned in their CAD databases and detailed drawings and disappeared. Unfortunately, this has caused constant turmoil and an utter lack of consistency towards later design projects resulting in no predictability whatsoever in the long term. They appear to have gained the least from the contest experience.

Although both traditional design courses have a design component, the degradation in grade consistency for all functions (students) reflects the fact that such a design component was relatively small when compared with the much larger design effort present in either ME Tools or the capstone project as seen in Fig. 6. The FYP seemed to have had a positive impact on rekindling, and perhaps improving, the design skills of some students as evidenced by the interaction improvement at year 5 following significant decreases at years 3 and 4.

8.3. Final course grade

With the exception that p values are more significant at years 4 and 5, the trends in Fig. 7 (course grades) resemble those of Fig. 5 (report grades). The weakened correlation at years 3 and 4 is in line with findings by Bailey [33] that analysis-heavy sophomore and junior classes do not impact design process knowledge. (In another similarity with Fig. 5, introducing the non-design courses (figure not shown) was found to add major bumps to the relatively clean trends in Fig. 7, which emphasizes the relevance of this study to design-related courses only.)

Figure 7 also shows that all team functions (except for analysts) display a late improvement in grade correlation consistency between ME Tools grade and the FYP course at year 5. This 'recovery' appears to have been regained at the assessment point corresponding to MECH 502 owing mainly to this course's heavy hands-on design tasks and to the format of this capstone course. One may think of connecting the end points, at year 2 with ME Tools and at 5 years with the FYP. The resulting line will assess the students natural 'dynamic mixing' over the 3 years separating these two defining courses. This would place the interactions for both traditional design courses above this line. One would hypothesize that this interactions 'difference' corresponds to the differences in course format between traditional and innovative courses. Therefore, one may think that changing the format of the traditional courses to a cooperative problem-based format would bring the interactions close to this hypothetical interactions line. A recommendation here would be for traditional design courses to incorporate a hands-on, intensive design component (preferably with a competition).

9. Lessons learned and conclusions

The study had answered both research questions I.1. and I.2 in the affirmative. Significant interactions between the team functions' grades in ME Tools and those in later design courses (including the final year project capstone course) are statistically established. However, interactions were observed to 'weaken' over time. While this may be partially explained by the expected (and, perhaps, uneven) growth in design knowledge amongst students, the evidence points to a possible lack of significant learning for some functions (and some deliverables) during the major design experience in ME Tools. This results in some student functions showing performance 'turbulence' in later design courses. Yet another source of poor interactions in later courses may be due to the dramatically different course format of the later traditional design courses. Therefore, improvements in the ME Tools course administration as well as in those of later design courses are recommended. Regarding the introductory course, more work on team intra-dynamics is needed so that a blended correlation is established across functions and not only with one's direct responsibility. More effort needs to be spent on teaching students the principles of teamwork so that more interaction can be achieved in the design of the micro-car. This recommendation falls in line with the best practices of cooperative learning where self-assessment of team functioning must be practiced. Self-assessment may be augmented by more active involvement of the direct team mentors (instructors and graduate assistants) who should also coach for better accountability and contribution of each team member regardless of the task function. A portion of the remedy may be achieved by mixing up the task functions and team functions in a fashion similar to that proposed by Gale and Knecht [11], who advanced the notion that team performance relies on a balance of task and team functions. As the project progresses, students can assume different functions, which would break the 'hard' task/team function divisions imposed by this course in its current administration. With regard to other design courses, it is recommended that the later traditional design courses be restructured to where design knowledge is acquired in a less traditional fashion by placing more weight on hands-on design projects, and that design learning is practiced in a team-based format.

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APPENDIX: RUBRICS USED IN ASSESSING ME TOOLS' REPORT

For the report component (worth 20% of the total course grade), each team member was assessed based on his/her function according to how close the below rubrics were met.

The Manager or 'the Big Wig': Rubrics related to defining/managing/documenting

1. Form the problem statement recognizing constraints and limits. **Assessment:** Precisely define 'top level' requirements based on the contest rules of choice (i.e. need variable power motor, adjustable gearing system, front wheel alignment, etc.). **Capture this in a Mission Statement placed on Pg. 1 of the report (M1=10%)**
2. Scheduling and planning. **Assessment:** Develop and update a complete and meaningful schedule using MS Project. Place MS Project in **Report Appendix 'A' (M2=20%)**
3. Management of Manpower (including disseminate information and flow of communications amongst team members). **Assessment:** Lead the team to meet project's timely deliverables through Team-held Design Reviews and Other. Weekly meeting minutes should be included as **Report Appendix 'B' in final report (M3=20%)**
4. Literature Search. Literature review of comparable products **(M4)**
5. Report documentation. **Assessment:** Overall report quality, format, and completeness (provide both a quality printed copy as well as a soft copy containing all CAD and analysis data (M5) **(M4 and M5 have a combined score of 50%)**

The Systems Engineer or 'The Big Picture': Rubrics related to formulating solution

1. Define design parameters and flow requirements into product specs. Translate requirements (verbiage) into engineering specification (numbers and values). **Assessment:** Detailed Product Specification (Product Requirement Document, PRD): Identify the contest leg(s) of strategic interest and technical requirement (i.e. *obstacle negotiation contest: need × torque N.m, min. wheel diameter, C.G. off the floor, ..). **Place Detailed PRD in the report's Appendix 'C' S1=30%)***
2. Product Configuration (Architecture). **Assessment:** Detailed Product Definition: Configuration tree (assigned part and assembly numbers) **(S2=10%)**
3. Identify alternative scenarios and select potential solution. **Assessment:** Develop a complete and meaningful Pugh Matrix **(S3=20%)**
4. Hand sketch complete system assembly. **Assessment:** Quality & completeness of hand sketches and components **(S4=20%)**
5. Research & development. **Assessment:** Specify cutting-edge components, materials, processes, etc. **(S5=20%)**

The Analyst or 'The Brains': Rubrics related to analyzing the design

1. Engineering and Mathematical solutions. **Assessment**: MATLAB, Excel, etc. Problem statements (i.e. shaft diameter, motor torque, distance traveled, acceleration, etc.) and documented solution (spreadsheet, MATLAB program, etc.). **Place complete package in Report Appendix 'F'**. **(A1=40%)**
2. Develop basic free-body diagrams. **Assessment:** Judged by the quality and completeness of **free body diagrams, F.B.D.**s **(A2=40%**)
3. Contest Winning Strategy. **Assessment:** Mathematical reasoning for strategically choosing a certain leg(s) and calculations proving design and strategy validity (i.e. *speed demon contest:* integration of acceleration to get velocity and integration of velocity to get distance of x ft target, etc.) **(A3=20%**)

The Details Designer or 'CAD Guru': Rubrics related to developing a detailed design

1. Develop detailed design using CAD drawings and other CAD database. **Assessment:** Overall quality and completeness of data base including detailed drawings and complete assembly layouts and CAD-generated photo-rendered figures. **Place complete CAD package in Report Appendix 'D'. (C1=90%).**
2. Develop other detailed mechanical documentation (bill of materials identifying source of components (vendor, cost, etc.). **Assessment:** Based on completeness of B.O.M. **Place in Report Appendix 'E'. (C2=10%).**

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