AC 2009-958: VEHICLE DYNAMICS AS A CONCENTRATION: CAPITALIZING ON BREADTH AND DURATION

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Vehicle Dynamics as a Concentration: Capitalizing on Duration and Topical Breadth

Abstract

A sequence of elective courses (a “concentration”) centered loosely around the subject of vehicle dynamics is herein proposed, and an example of its implementation is described in considerable detail. The component courses are selected so as to impart to the concentration, to the maximum practicable extent, two characteristics thought to be desirable: topical breadth, i.e., exposure to a range of engineering topics that relate to and intersect with vehicle dynamics, as well as a conscious effort to favor, instead of specialization, a broader interpretation of what constitutes a vehicle – inclusive of a variety of modes of transport; and, duration, i.e., lasting and repeated exposure to the central topic of vehicle dynamics at different stages of the curriculum.

It is demonstrated by means of course and curricular assessment that these characteristics are realizable, and that they impart several benefits, including: improved student retention, accessibility of the sequence to multiple engineering disciplines, flexibility to accommodate transfer students, reinforcement of engineering core subjects, and versatility of the engineering graduate.

1. Introduction

In engineering curricula, vehicle dynamics is very often available as a single upper level elective course, giving the student a first exposure to the topic relatively late in the curriculum, and then ordinarily in the spirit of a specialized topic. As an alternative, it is proposed here that vehicle dynamics can serve well as a common thread running through a sequence of elective courses (often referred to as a "concentration" or "option"), each of these selected according to a philosophy that seeks to maximize two main characteristics of the concentration: *topical breadth* and *duration*.

Topical breadth is sought at several different levels: at the curricular level (a range of course topics), at the level delimiting vehicles (a range of vehicle categories), and at the level of methodologies (experiment, analysis, simulation, etc.).

Duration, secondly, is meant in the sense of repeated, and nearly continuous, exposure to vehicle dynamics examples at different stages of the curriculum, underclass through upperclass.

Rather than mere ends in themselves, this work postulates that topical breadth and duration will serve as means to more unambiguously beneficial ends, such as improved course enrollments and student retention, accessibility of the sequence to multiple engineering disciplines (with common elective courses between the disciplines), flexibility to accommodate transfer students, reinforcement of engineering core subjects, and versatility of the engineering graduate.

The vehicle concentration so constructed has clear parallels to cases elsewhere in which a focused concentration within an engineering degree program is based upon a theme that would more conventionally correspond to an upper-level technical elective. For instance, Hsu[1] has described a similar approach to developing a concentration based on Mechatronics. Landsberger et.al.[2] design an entire degree program on the theme of energy production, incorportating energy-related examples throughout fundamental Mechanical Engineering courses, to complement those in the focused technical electives. The idea of implementing a pedagogical concept throughout the curriculum, what is referred to as *duration* here, is documented elsewhere as well; for instance, Mokhtar et.al [3] describe this principle in terms of open-ended student projects, which are implemented right from first-year courses all the way through to graduation. Yim et.al.[4], in designing a new program, emphasize exposure to engineering as early as the freshman year, when students are otherwise typically in math and science courses, as a tool to retain students in engineering. The concept of making common use of electives between disciplines in a concentration is also documented elsewhere, such as between Electrical and Mechanical Engineering in the Robotics concentration at the University of Southern Maine (Smith[5]).

This paper will address, in turn, the twin philosophical underpinnings of the concentration – topical breadth and duration, after which a detailed example of the implementation of such a concentration is provided, and, finally, benefits deriving from adherence to the stated philosophy are demonstrated with the support of assessment results.

2. Topical Breadth

Topical breadth is meant in at least three different senses in the present context: firstly, in the sense of a close association of the central subject of vehicle dynamics to a range of other related subjects, and especially core subjects in the engineering disciplines; secondly, a broad interpretation of what constitutes a "vehicle", as opposed to any more narrow specialization to a specific vehicle category; and, thirdly, a good balance of experiment, theory, and simulation.

Breadth, in all of these senses, is consistent with the notion that the purpose of an undergraduate education is not to produce a narrow specialist, even while providing an opportunity for focus in an area of special interest to the student.

2.1 Curricular Breadth

One aspect of topical breadth is at the curricular level; it implies constructing the concentration from courses with varying degrees of vehicle focus. Thus, besides a dedicated "vehicle dynamics" course itself, it would also include courses that are vehicle-relevant, but not vehicle-specific.

Examples include such topics as Instrumentation and Testing, Vibrations & Acoustics (or NVH – Noise, Vibration & Harshness), GD&T (Geometric Dimensioning & Tolerance), Signal Processing, Rigid Body Dynamics, and others. Characteristic of such topics is that they can be favorably complemented by occasional examples involving vehicles, but other illustrative applications of these subjects are not necessarily excluded; of course, the vehicle-related examples need not be so heavily emphasized that they skew these courses from fulfilling their separate objectives which serve other purposes than merely those of the proposed concentration. One might reasonably expect that a student, with a particular interest in vehicle dynamics, would be motivated by such examples to better appreciate the specific subject area of the course concerned.

Conversely, in the dedicated vehicle dynamics course, which presumably comes late in the curriculum just as in the traditional model, the ties made earlier to core subjects might offer better opportunities to reinforce those subjects; in the context of the vehicle dynamics course, they serve as tools. Numerical methods, rigid body dynamics, and signal processing are all examples of prime candidates for such reinforcement in the vehicle dynamics course.

A philosophy of topical breadth also suggests a degree of flexibility in the composition of the sequence, which permits it to be open to students with differing core disciplines (Mechanical Engineering, Electrical Engineering, etc), and also more easily accommodates transfer students.

2.2 Breadth of Vehicle Categories

Whereas the traditional interpretation of “vehicle” is fairly restrictive (often implying “automotive”), a philosophy of topical breadth suggests a broader interpretation, inclusive of such vehicle types as off-road, articulated, railway, maritime, and/or aerospace, as well as automobiles.

Such an interpretation lends itself to instruction addressing both unifying and distinguishing aspects of dynamic behavior by vehicle category. A student with this broader perspective could reasonably be expected to become a more versatile engineer. Breadth in this sense should probably also widen the appeal of the concentration to prospective students with a wider range of interests (ATV enthusiasts, sailors, etc).

2.3 Breadth in Methodology

Finally, it would be consistent to also apply the philosophy of breadth at the level of methodologies used to study vehicle behavior, by seeking a balance between experimental work, theoretical analysis, and simulation (and even at that level, using both dedicated commercial software and student-written code). Such a balance also contributes to versatility of the engineering graduate.

3. Duration

Duration implies that the elective courses are available at different stages throughout the curriculum, even in underclass-level courses. This circumstance offers the student nearly continuous exposure to vehicle dynamics, thereby gradually building a maturity in the subject area.

Early underclass courses that touch on vehicle dynamics can introduce some of the main issues of the field, while later upperclass courses come at a stage at which they can synthesize knowledge from core courses.

An expected benefit of the earlier-than-traditional exposure to vehicle dynamics is that the student, who is often directly motivated by an interest in vehicles, would likely gain motivation to persevere through core courses, given the attractiveness of the vehicle-related examples. Furthermore, it should appeal to such a student to be able to satisfy such interests right from the underclass level – for some underclass students, a potential elective course in the senior year is rather too abstract and distant to provide alot of motivation. Likely, for each of these reasons, "duration" should help in the retention of such a student.

4. Implementation

Concentrations of elective courses, selected in accordance with the principles expounded here, have been implemented at Lake Superior State University (LSSU), where they are referred to as *options* instead of concentrations (as may be more conventional). These options are available in both the Mechanical and the Electrical Engineering degree programs, and some of the component courses are also open as free electives for Computer Engineering and Manufacturing Engineering Technology students as well.

Below, a brief overview is provided of how each of these options have been structured and how they fit into the respective degree programs, content of the component courses, and some of the pedagogical approaches undertaken to achieve the goals of the options.

4.1 ME Curriculum Example

A *Vehicle Systems Option* was established within the Mechanical Engineering Program at LSSU beginning in the Fall 2007 semester, replacing a previously-existing *Design Option* that suffered from a lack of enrollment. Since then, it is one of two focused technical elective options available for ME students, together with the *Robotics & Automation Option*; there is also a *General Option* in which the student more freely composes a set of technical elective courses (possibly including some from the vehicle systems option). Table 1 lists the set of courses comprising the *Vehicle Systems Option* for the ME degree program.

Table 1. ME Vehicle Systems Option at LSSU

Course Number	Course Title	Cr.	Prerequisite Topics
EGME240	Assembly Modeling and GD&T	3	CAD
EGME310	Vehicle Development & Testing	2	Statics, Physics
EGEE365	Vehicle Instrumentation	4	Circuits, C programming
EGME415	Vehicle Dynamics	2	Dynamics, Numerical Methods (incl Differential Equations indirectly)
EGME425	Vibrations & Noise Control	4	Dynamics, Numerical Methods,

			Differential Equations, Multivariable Calculus, Strength of Materials

The option stretches from the second through the fourth curricular years (duration). It spans both ME and EE listed courses, noting the EE-listed vehicle instrumentation course, in particular (curricular breadth). Within the set of ME courses, it includes topics like GD&T and Vibrations & Noise Control that are more general in their applications than the theme of the option (curricular breadth). At the level of fourth-year courses, both Dynamics (meaning classical particle and rigid body dynamics) and Numerical Methods are common prerequisites, applications of which are emphasized in the option courses that follow.

4.2 EE Curriculum Example

Table 2 lists the courses comprising the *Vehicle Systems Option* in the Electrical Engineering program at LSSU. This option was established in Fall 2008, a year after its ME counterpart.

Table 2. EE Vehicle Systems Option at LSSU

Course Number	Course Title	Cr.	Prerequisite Topics
EGEM320	Dynamics	3	Statics
EGME310	Vehicle Development & Testing	2	Statics, Physics
EGEE365	Vehicle Instrumentation	4	Circuits, C programming
EGME415	Vehicle Dynamics	2	Dynamics, Numerical Methods (incl Differential Equations indirectly)

Note that a significant overlap of elective courses with the ME vehicle systems option was consciously built-in; of course, this has the benefit of bolstering enrollment in these courses.

4.3 Course Content & Objectives

Table 3 lists, for each of the component courses of the two options presented above, the instructional formats, i.e., respective weekly lecture and laboratory hours allocated, and the specific course objectives (as tracked in the course assessment schemes).

Table 3. Instructional Format & Course Objectives of the Electives

EGME240 Assembly Modeling & GD&T **2 Lec hrs/ wk, 3 Lab hrs/wk** 1. Be able to use CAD software to prepare prints with GD&T symbols. 2. Be able to apply GD&T to simple assemblies. 3. Be able to effectively create solid parts and construct assemblies. 4. Be capable of using current CAD solid modeling and animation software to create effective presentations. 5. Be able to effectively write memos and reports. 6. Be able to conduct design review	**EGEM320 Dynamics** **3 Lec hrs/ wk** 1. Analyze motion and acceleration of particles and rigid bodies using kinematics principles. 2. Analyze forces associated with particles and rigid bodies as they are accelerating. 3. Analyze moving particles and rigid bodies using energy methods to determine forces and velocities. 4. Analyze moving particles and rigid bodies using impulse and momentum methods for forces and velocities. 5. Analyze a physical problem, develop experimental procedures for accurately investigating the problem, and effectively perform and document their findings. 6. Use commercial software packages to model dynamics problems (e.g., perform numerical integration, direct dynamics system simulations).
EGME310 Vehicle Development & Testing **1 Lec hr/ wk, 2 Lab hrs/wk** 1. Describe how the dynamic performance of a vehicle is tested using appropriate transducers and instrumentation, and how that equipment is mounted to the vehicle; 2. Explain the main principles of vehicle benchmarking; 3. Explain the main principles of gross vehicle dynamics, including acceleration, braking, cornering, and ride; 4. Explain the principles of the design of vehicle subsystems, including tires, brakes, steering, and suspensions, as well as the respective influences of these subsystems on the gross vehicle dynamics; 5. Use a commercial vehicle dynamics software package to study the influence of parameter changes on a vehicle's dynamic performance.	**EGEE365 Vehicle Instrumentation** **3 Lec hrs/ wk, 3 Lab hrs/wk** 1. Write data acquisition programs using LabVIEW foundational operations. 2. Design scalable programs using typical design patterns and advanced structures. 3. Develop programs that interface and use typical data acquisition hardware. 4. State the structure of small area networks and standard CAN protocols. 5. Analyze the operation of CAN networks. 6. Design and simulate the operation of CAN networks.
EGME415 Vehicle Dynamics **2 Lec hrs/ wk** 1. Explain, and dynamically model, the influence of parameter changes in component design (e.g., tires, body mass and CG, suspension, steering, etc.) on automotive vehicle dynamic performance (e.g., acceleration, cornering stability and understeer gradient, ride, drag and rolling resistance, noise & vibration, etc.). 2. Explain the underlying physics, and dynamically model, off-road vehicles on soft terrain. 3. Explain the underlying physics, and dynamically model, articulated vehicles such as heavy trucks. 4. Explain the underlying physics, and dynamically model, railway vehicles. 5. Explain the physics of phenomena related to vehicles in other media, such as watercraft, and compare and contrast their dynamics of to that of land vehicles.	**EGME425 Vibrations & Noise Control** **3 Lec hrs/ wk, 2 Lab hrs/wk** 1. Analyze the vibration of discrete (sdof, mdof) systems, both free and forced. 2. Analyze the vibration of simple continuous systems. 3. Qualitatively distinguish the behavior of non-linear, from linear, vibrating systems. 4. Identify and design vibration control (mitigation) measures. (isolation, tuned absorption, damping, excitation frequency modification, resonance tuning, added masses, seismic masses, balancing, etc.) 5. Identify important causes of machinery vibrations. (imbalanced rotors & shafts, gear meshing, blade pass, bearings, cavitation, oil whirl, etc.) 6. Analyze sound fields in air, both unbounded and bounded. (homogeneous air, thermal gradients atmospheres, planar reflectors, rooms as lumped elements, rooms as resonant fields, rooms as diffuse fields, rooms as geometrical acoustic fields, ducts) 7. Identify and design noise control (mitigation) measures. (resonance tuning, source placement in resonant fields, absorption, insulation, radiation reduction, mufflers/silencers, vibration reduction as noise control) 8. Describe methods to measure sound and vibrations. 9. Identify the essential aspects of human hearing and subjective experience of sound. (physiology of the ear, A-weighting, equivalent time-averaged sound levels, phones, masking)

As is evident from the table, certain courses (Assembly Modeling and GD&T, Vibrations & Noise Control, Dynamics) within the options have course objectives (and hence course content) that are far more general than vehicle engineering. It would be contrary to the philosophy of the option to remold these in an attempt to infuse vehicle dynamics throughout. However, each of these courses does make use of lecture examples, homework problems, and/or course projects that are vehicle-related, as detailed in the following.

The *Assembly Modeling & GD&T* course includes a team design project, in which the outcome is a set of technical drawings and animations of parts and assemblies, and a technical report. Although almost any type of assembled machine or structure would serve the *course* objectives as the object of a design project, the *option* goals, on the other hand, are more specifically supported by selecting a vehicle subsystem as a design project. Accordingly, examples from recent years have included the redesign of the steering system of a garden tractor, a boom for a skid steer, and others.

The *Vibrations & Noise Control* course supports the theme of the option by means of a lecture unit on automotive muffler analysis, some specific homework problems related to automotive NVH (e.g., cylinder resonances in an internal combustion engine; resonances in the cabin space of a bus; vehicle pass-by noise in a park), and a term project involving predicting the vibration level at, and isolating, the CD player in an automobile; this latter project gives a good independent introduction to vehicle ride analysis.

The *Dynamics* course, a core course in ME with more of a fundamental than an applied bent, but also an elective in the EE vehicle option, has three mini-projects. One of these involves fuel economy analysis of a snow plowing vehicle, and another of these, in some years, has centered on the dynamics of railway track-car interactions.

Of course, the other three courses in the two options all have “vehicle” in their respective titles, and a nearly exclusive degree of vehicle focus. Notably, the *Vehicle Dynamics* course implements the idea of topical breadth in the sense of vehicle categories, covering such divergent topics as, for instance, rolling resistance of automotive tires, analysis of tractor-semitrailer jackknifes, drawbar analysis of tractors on soft terrain, snowmobile steering principles, railway wheel hunting, wave resistance of boats, roll frequencies of ore freighters, and wind tunnel testing principles for aircraft. In contrast, *Vehicle Development & Testing* is more focused on automobile performance and subsystems (with a little bit of contrast and comparison to off-road vehicles as well). The *Vehicle Instrumentation* course is dedicated to an overview of digital communications and signal handling within automobiles, principally, although the applicability of the content also extends to recreational boats, among other things.

4.4 Pedagogy

Pedagogical approaches employed in the option to date have been chosen to emphasize the methodology aspect of topical breadth. This aspect is more dependent on the pedagogical methods than on any prior selection of course content, although judicious selection of appropriate prerequisites for the option courses (and most notably numerical methods) does lay the groundwork for these pedagogical approaches. The following have been particularly favored approaches in the option courses thusfar:

- Open-ended project work;

- Some instruction by practicing engineers (experts in vehicle testing and dynamics);

- A good balance of experiment, theory/analysis, and simulation (and between "canned" and original software in the case of simulation).

Addressing each of these in turn, examples are presented to clarify.

Open-ended project work is in accordance with a wider departmental philosophy for all LSSU engineering courses (see Mokhtar et.al.[2]), but has extra emphasis here, and the additional advantage of tying together the sequence of elective courses. Accordingly, term projects are required in several of the option courses: *Vehicle Dynamics*, *Vibrations & Noise Control*, *Assembly Modeling & GD & T*. Furthermore, some courses, like *Dynamics* make use of multiple mini-projects. Example topics have been provided above, in the discussion of course content, for all of these courses except the first. *Vehicle Dynamics*, notably, has a very open-ended term project carried out by 2-3 student teams which choose their own topics. The only constraints on the topic are: 1) that it relate some aspect of vehicle performance (for any kind of vehicle) either to vehicle design parameters or to properties of the transport medium (road surface, wind speed, terrain plasticity, etc.); and, 2) that a systematic parameter study, either experimental or numerical, must be included. One student project, for instance, measured how snow depth and quality on the road influenced ride vibrations; another successfully predicted the acceleration performance of an off-road vehicle, later built in a senior project course for a summer SAE competition, on varying terrains.

Including some instruction by practicing engineers is intended to take advantage of their expertise and practical perspective, to give the students exposure to practice while still in their degree programs, to help form contacts between graduates and industry, and to increase confidence in the currency of the content. To that end, the *Vehicle Development & Testing* course has been co-instructed by a regular faculty member and one to two experienced vehicle test engineers. The proportion taught by the practicing engineers has varied from about 1/3 up to about 3/4 of that particular course.

Experimental techniques, theory / analytical methods, and simulation are each well-represented in the option.

The *Vibrations & Noise Control* course has a significant laboratory component dedicated to measurement and signal analysis of sound and vibrations. The *Vehicle Development & Testing* course and *Vehicle Instrumentation* courses are projected, beginning Fall 2009, to make extensive use of a newly-installed chassis dynamometer for such purposes as finding torque-rpm and horsepower-rpm curves, measuring drivetrain vibrations, communicating with an automobile through its CAN network, etc. Previously, these courses have also included laboratory measurements of such things as engine vibrations, of vehicle inclination in cornering, and vertical accelerations experienced by and off-road vehicle in landing from a jump.

Theoretical understanding, and analytical methods, are represented at many levels. For instance, the *Vehicle Dynamics* course seeks to relate plastic properties of terrain to resistance faced by an off-road vehicle, delves into the relation between relaxation phenomena in rubber and tire rolling resistance, and seeks to find critical speeds of vehicles on ice sheets in terms of plate wave speeds in the ice;
the *Vibrations & Noise Control* courses delves into the effectiveness of sound absorptive material in an enclosed space (e.g., interior of a passenger railcar) in terms of Sabine's theory, and seeks to explain the behavior of a reactive muffler in terms of transmission-line theory; *Vehicle Development & Testing* explains automobile tracking and cornering in terms of the understeer gradient; *Dynamics* is a principally theoretical course covering particles and rigid bodies; etc.

Simulation, specifically, is covered by attention to both dedicated, commercially available software and to the implementation of numerical methods by student-written programs. The former is exemplified by the use of CARSIM, a comprehensive multibody dynamics software for analyzing automobiles, as an instructional tool in the *Vehicle Development & Testing* course; this might be used, for instance, to demonstrate how tire camber from suspension travel affects cornering ability or steering effort. An example of simulation using original code, from the *Vehicle Dynamics* course, would be that of writing a Runge-Kutta algorithm to figure automobile stopping distance in a continuous turn (e.g., circular off-ramp), accounting for increasing available braking coefficient as the demand for cornering stiffness decreases with falling speed.

5. Outcomes

Formal course assessment reports are available from each offering of each course, and provide some basis for analyzing the extent to which the postulated benefits of the concentration have been obtained. However, at present, the option is so new that the quantitative data is as yet relatively meager; the analysis is therefore very reliant on the qualitative assessment results available (e.g., language of course objectives, etc.).

Several benefits were postulated at the outset: improved course enrollments and retention, accessibility of the sequence to multiple engineering disciplines, flexibility to accommodate transfer students, reinforcement of engineering core subjects, and versatility of the engineering graduate.

The enrollments of all courses in the *Vehicle Systems Option* are tracked in table 4, including a couple of years before the establishment of the option (given that some of the courses existed prior to that, and a couple of the newer courses were given as special topics the year before the option became active).

Table 4. Enrollments by year in Vehicle Systems and Design Option Courses

— indicates a course not offered

** indicates EGME240 as a core course (with large enrollments including students from *all* ME options)

(3) indicates a restricted course offering in directed study format, with 3 students

Some courses (EGME 310 and EGME415) have undergone course number changes, in which case the equivalent current course number is used (regardless of the actual course number used in the academic year concerned).

	New Courses for Option			**Option Courses Previously Existing**	
Academic Year	**EGME 310**	**EGEE 365**	**EGME 415**	**EGME 425**	**EGME 240**
2005 -6	—	—	—	4	25 **
2006 -7	13	—	2	—	20 **
2007 -8	5	10	6	12	11
2008-9	12	—	7	(3)	14

It is clear that the new courses have attracted significant enrollments (compare to a current total enrollment in the entire ME program of 59 for 2008-9, a fairly representative figure; thus, a quarter of that, or about 15 students, is the typical pool available at any given stage in the 4-year curriculum). Of the previously existing courses, the EGME425 course has expanded its enrollment significantly, and EGME240 has retained a large share of it, considering it has been removed from the ME core.

Retention within the option is also to be considered. Table 5 shows that most ME students who began the *Vehicle Systems Option* by enrolling in EGME310 (the vast majority had earlier taken EGME240 as a core course before the option was introduced) succeeded in that course and eventually took EGME415. The composite turnover for all three academic years in which the courses have been offered is 88%, if one discounts those students who graduated immediately after taking EGME310 before EGME415 was offered again (evidently, these took EGME310 as a free elective before the option existed). The turnover ratio is actually 94%, however, if one considers only EGME310 students who have completed the other necessary prerequisites to date. This data suggests that retention from the 3rd to the 4th year in the option is good. One might extrapolate an expectation that the option will contribute to student retention in general.

Table 5. ME Student turnover (from EGME310 to EGME415)

* figures in parentheses discount EGME310 students who have yet to complete other EGME415 prerequisites.

	Enrolled in EGME310 (ME only)	… and did not graduate before next offering of EGME415	Eventually took EGME415 (or equiv earlier course no.)	Turnover Ratio
2006 – 2007	6	3	3	1
2007 – 2008	5	5	5	1
2008 – 2009	9 (8) *	8	7	.78
All Years				.88 (.94) *

The adaptability of the option to different core curricula has already been evidenced by tables 1 and 2; i.e., the option is now available in both the ME and EE programs, albeit in slightly different forms. At the course level, furthermore, the *Vehicle Development & Testing* course has, since its inception, also been taken by 6 students in Manufacturing Engineering Technology and 1 in Industrial Technology, these students providing over 25% of its total enrollment. All of these students have passed the course, and their average grade has been 2.4 / 4.0, compared to 3.1/4.0 for these classes as a whole. While their average grade is somewhat lower than for the other students, it is still more than satisfactory.

Transfer students can also be accommodated by the option structured as designed. The goal of duration, i.e., the span of the option over several academic years, would, at first, appear to preclude that. However, consider the specific case of an ME transfer student, new to LSSU in the Fall 2009, entering with a credit count equivalent to around two years at LSSU (a very common level for transfer students, who often study 2 years at a community college). This student transferred in most of the prerequisites listed in table 1, excepting only numerical methods. The EGME310 and EGME240 courses were immediately accessible, and the numerical methods prerequisite was also accessible (in the 3rd year, as for most other ME students). Thus, this student is on track to complete the degree, with the option, in the 4th year.

Another benefit to be assessed is that of reinforcement of the content of core courses by the option courses. Let us concentrate on Dynamics and Numerical Methods, as reinforced by the ME vehicle option. Firstly, as is evident from table 3, all but one of the objectives in *Vehicle Dynamics* include the phrase "… , and dynamically model,…", clearly evidencing that the intent is not merely to understand some particular vehicle category, but moreover to investigate it using analytical tools from both of the prerequisites mentioned. As the above discussion of simulation content in courses highlights, this intent is made concrete by way of assignments requiring student-written numerical algorithms. Although the subjective experience of the instructors does suggest that this translates into improved mastery of the core topics, there is no quantitative data available as yet to bear it out. A likely source of data to make this assessment would be performance of students on the FE exam, comparing performance in dynamics (for instance) between those who have and those who have not taken the option; the initial set of graduates (6) is too small to have provided any such data so far.

Versatility of the graduate will also have to be assessed after a larger pool of graduates exists. Versatility would commonly be understood to mean, in this context, the ability to work professionally in a variety of vehicle industries and to fit into a variety of engineering roles within those industries (analysis, testing, design, project work, etc.). Internal assessment data is available to support a part of this definition. Specifically, figure 1 shows the composite student confidence level and grade performance of all students in the first 2 offerings of *Vehicle Dynamics* made since the course's inception in 2005 (data for the current offering will not be available until the summer of 2009).

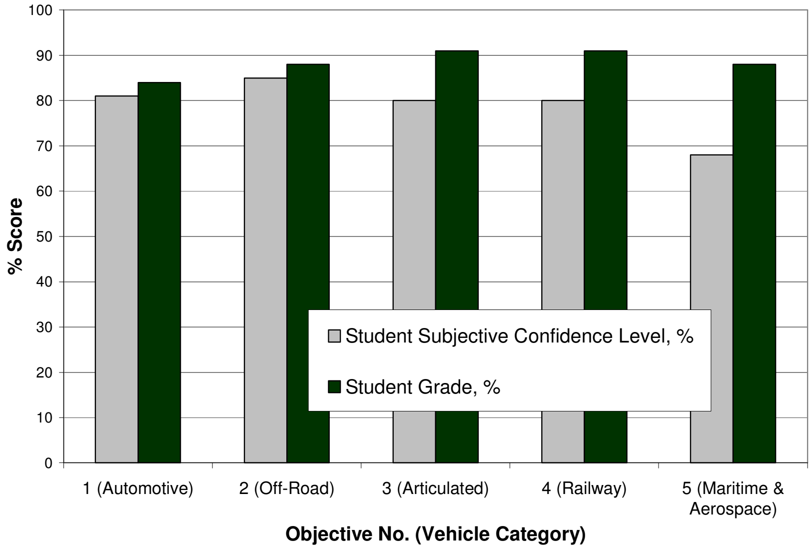

Figure 1. Composite student confidence level and grade performance in *Vehicle Dynamics* course objectives (see detailed objective descriptions in table 3)

The objectives can be read in detail in table 3, but each essentially refers to competence in understanding a specific vehicle category. Evidently, the grade performance is good in all cases, reflecting that the instructors felt a strong degree of confidence in the students' abilities. The student confidence level was high in all categories, as well, excepting the maritime/aerospace category; regrettably, practical reasons dictated that the assessment questionnaire obtaining this statistic was circulated before instruction on this topic was completed in the course, so the low score likely reflects that circumstance.

What is lacking here, however, is any external calibration of such data. Tentatively, the only supporting external data is knowledge that current option graduates are working in more than one vehicle-related industry (at least one in maritime, and at least one in automotive, others unknown).

6. Conclusions

It has been demonstrated that the topic of Vehicle Dynamics is a viable basis for a concentration within various Engineering disciplines. A workable philosophy, which results in clear benefits, is to maximize the topical breadth and duration within the concentration. Assessment data show the philosophy advocated here can contribute to gains in class enrollment and student retention, by providing an attractive theme for an elective sequence. The concentration created according to the principles advocated can also be made flexible enough to accommodate students of differing core disciplines – Mechanical Engineering and Electrical Engineering majors in the example described (as well as other majors in some of the courses). Transfer students can also be accommodated, as a specific example demonstrates. It is also probable that the elective courses serve well to reinforce specific core courses that serve as prerequisites, notably rigid body dynamics and numerical methods in the example concentrations discussed. Demonstrably, the elective course objectives can be written so as to promote use of prerequisite knowledge and skills. However, assessment data is as yet too scarce to support any assertion that these skills are measurably improved thereby. Similarly, the option, as described, likely makes for a versatile graduate, capable of working professionally in various vehicle-related industries, but graduates of the options discussed are too few as yet to make any quantitative assessment.

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