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Introductory Vehicle Energy Systems Instruction Initial Experiences and Development

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Introduction:

The transportation energy sector is changing with new and expanded complex systems. The result of the change is fostering a fresh look at the need to review and revise vehicle energy systems instruction. This need is based upon on-going development in the electrical, mechanical and hybrid systems in all sectors of vehicle systems. In our world today individual communication and corresponding individual mail and parcel delivery systems are being redefined. Autonomous transportation systems are emerging. Advanced architectures for vehicles may redefine refueling from gas pumps to charging from wireless charging systems even while the vehicle is moving.

The emerging engineering and technical workforce will be responsible for birthing the future transportation systems. They will expect fresh views, new and developing instruction, and the ability to define and create what now can only be imagined. Just like those who put a man on the moon, the engineers that we are now teaching will create a transportation sector that we can only imagine. We may not see or experience what they create, but we are responsible to prepare them.

The foundation for this paper is based on the author's 40+ years of teaching electrical engineering, and many recent years of consulting in vehicle systems engineering as a Vehicle Systems Electrical Engineer at WaveCrest Labs, BlueWave Systems, and Magna Corporation. That engineering work focused on developing and maintaining dynamometer and testing systems for electric\hybrid vehicle power train components and related systems. That combination of years of consulting and teaching helped create the foundation for the course.

The course is specifically required for mechanical engineering majors who have elected the vehicle systems concentration within mechanical engineering. Other students who meet the basic course requirements of Electrical Circuits, and Physics are welcome to take the course as a technical elective.

Course Format and General Content:

The Vehicle Energy Systems course involves a typical lecture and laboratory format with two lecture hours and a three-hour laboratory each week. The initial lecture content briefly reviews fundamental electrical and mechanical basics, and applies basic DC, single phase and three phase AC content as well as power and electrical machinery fundamentals. The course also includes computer simulation of energy systems via use of MATLAB-Simulink SimPowerSystems modeling, and the simulation of vehicle applications using Vector CANoe vehicle software.

The laboratory component uses several major resources. An electrical machinery laboratory supports electrical machinery testing, single and three phase systems, and energy transfer. An eddy-current vehicle chassis dynamometer and access to a test vehicle also enhance the vehicle testing instruction. The dynamometer controller is an industry standard control system with LabVIEW Real Time data acquisition and control software and hardware. Performance indicators can be acquired via the dynamometer instrumentation, additional external instrumentation, and access to the vehicle CAN bus. The CAN bus and the vehicle's Data Base support data acquisition instruction and enable vehicle performance evaluation on real world equipment.

The course uses vehicle energy systems as a platform to review and reinforce fundamental engineering approaches and calculations while presenting recent, relevant vehicle energy systems technology. The course also provides an opportunity to evaluate alternate approaches and designs by making engineering judgments and decisions that are common in day-to-day engineering practice.

The course structure includes a combination of lecture, simulation, and laboratory learning experiences. A standard textbook is not required; however, the textbook Hybrid Electric Vehicles: Principles and Perspectives [(1)]ISBN-13: 978-0470747735 by Mi, Masrur, and Gao is recommended. These individuals have immense academic, development and field experience in the content area. The author had the opportunity recently to complete a graduate course in this area from Dr Masrur at University of Detroit Mercy. Dr Masrur is employed full time in electrical/hybrid vehicle engineering industry.

Pre-Course Work:

The EGNR362 Vehicle Energy Systems course is a junior level course. The prerequisite course content includes MATLAB, DC & AC Circuit Analysis, Calculus, Differential Equations, and Laplace. That content is used in the EGNR362 course from the start. A course in Electrical Machinery is a definite asset, but not considered a prerequisite.

MATLAB/Simulink is used in the course. Prior to course start the students receive an email greeting from the professor with a copy of the syllabus. The content of the greeting makes it clear to the students that they will use MATLAB and Simulink in the course, and recommends that they know those skills. They are advised to work through the Simulink tutorials at MATLAB prior to start of the course at https://www.mathworks.com/academia/student_center/tutorials.html [2].

Prior to the course start, the students are sent a 26 page packet of review material. This material begins with a brief review of the unit circle - complex numbers - phasors – sinusoidal waveforms, as well as a review of Energy, Power, Voltage, Current, and motor Speed-Torque-Horsepower. The review content also includes basic transformer and a conventional DC machine model problems and solutions. In addition the document also presents regeneration, dynamic braking, and basic transformer, single-phase and three-phase example problems. Laplace and Differential Equation content is also included in the review material.

Course Content - Introduction

The course content introduction presents issues related to the heavy dependence of fossil fuel-related transportation for economic and social development, and discusses the serious challenge in energy demand and supply as well as the consequences of emissions.

Existing personal transportation systems are not sustainable in the long run. China surpassed the United States in 2009 to become the second largest vehicle market in the world, with more than 13 million motor vehicles sold in 2009. China used to be self-sufficient in oil supplies, but is now estimated to import 40% of its oil consumption.(1) Other industrialized countries such as Japan, Germany, India and Brazil have seen tremendous growth in car sales.

The history and projections of oil demand and production support the belief of the theory of peak oil at the present time. Basically, the theory predicts that oil production is at its peak in history, and will soon be below oil demand and possibly create an energy crisis.(1) Economic growth relies heavily on energy supply.(1) Emissions from fossil fuel are the primary source of Green House Gas.(1) The emissions of a typical passenger car are highest during a cold start because the catalytic converter needs time heat up to approximately 350 degrees C in order to function efficiently.(1)

The US Government announced the CAFÉ standard in 2009 requiring that all car manufacturers achieve an average fuel economy of 35 MPG by 2020. To achieve this goal, a mixed portfolio is necessary for all car manufacturers. “Auto makers must shift from large cars and pickup trucks to smaller vehicles to balance the portfolio. Auto makers must continue to develop technology that supports fuel efficiency improvements in conventional gasoline engines. Auto makers have to increase development and production of Hybrid Electric Vehicles and Plug-in Hybrid Electric Vehicles."[(1)]

The introductory course content also looks at the typical architectures of combining two energy sources in the same vehicle: Series HEV, Parallel HEV, Series-Parallel HEV, and Complex HEV. All topologies are also applicable to diesel hybrids.

The System-level diagram of an Electric Vehicle is discussed in class. This discussion shows the Communication Bus, High Voltage Bus, and general overview of low voltage, communication buses, and peripheral loads that make up the Electric Vehicle Power Train (EVPT).

The concept of hybridization of the automobile presents the fundamental operation of ICE engine, transmission, vehicle load, and engine characteristics as well as typical automotive Drive Cycles. The System-level of an Electric Vehicle Powertrain is presented and discussed. The major components of the Electric Vehicles are introduced, and the system-level of the Plug-In Hybrid Electric Vehicle (PHEV) is discussed.

Hybrid Electric Vehicle Fundamentals and Powertrain Architectures

The hybrid instruction introduces hybrid electric vehicles that combine an Internal Combustion Engine (ICE) with an Electric Motor (EM). This enables regenerative braking, supports reduction of idling and a more efficient system. The hybrid system helps to reduce fossil fuel consumption and reduce emissions.

HEV fundamentals instruction introduces road load modeling and calculations of rolling resistance, aerodynamic drag, road load that depends on road grade, vehicle mass, road angle, and gravitational acceleration. Drive Cycles are discussed and sample calculations performed. These factors affect vehicle performance and fuel economy.

The Series HEV power train calculations are performed and discussed, and the Internal Combustion Engine (ICE) speed-torque characteristics are reviewed at several gear ratios.

Planetary Gear Trains are used to replace the traditional automatic transmission and provide an electric continuous variable transmission. The planetary gear train has a sun, planet, and ring axis. The three shafts of the planetary gear train allow any shaft to be the input or output shaft. The Toyota Prius is used as an example of planetary gear train. The engine, motor, and generator combine to form a continuous variable transmission or Electric Continuous Variable Transmission. Students complete an exercise of evaluating the gear ratio and torque-speed values for various loads.

Plug-in Hybrid Electric Vehicles

A survey revealed that 78% of the US population drives an average of 40 miles or less in their daily commuting. If the owner drives less than 40mph they can "plug-in" their vehicle and charge it at night. Wireless charging can also remove the need to plug in the vehicle at night, and there is also the possibility of wireless charging during driving.

Planetary Gear Train

The traditional automatic transmission is replaced by a planetary gear train in many hybrids. An excellent, interactive, demo of the Toyota Prius – Power Split Device (PSD) is available online at eahart.com/prius/PSP. The students use this interactive demo when studying the gear ratio and torque-speed values.

In-Vehicle Communication Instruction

Information transmission between various functional blocks or groups occurs with a Controller Area Network (CAN) bus. The CAN bus is basically a two-wire system or single-wire (with chassis ground return) that carries information or communication signals multiplexed together. The Vector CAN and CANoe software environments are used for CAN instruction. CANoe may be used for CAN simulation. The Vector CAN case is used for the CAN connection and license.

MATLAB/Simulink/SimPowerSystems

MATLAB is used in Vehicle Systems in industry for data analysis, and Simulink is used for simulation applications. Simulink is also used as the control software in motor controls, and translated to appropriate machine code when downloaded to the motor controller.

Engineering students take the EGNR140 Linear Algebra & MATLAB course in the first year. MATLAB is reinforced within engineering courses on a course by course basis. Simulink is not part of the typical engineering education, but Simulink is introduced in the vehicle energy course. Prior to the start of the course, the students are advised to review the Simulink User Tutorials that are available on the Mathworks website. An introduction to Simulink is the focus of an introductory laboratory session, and that material is reinforced in short exercises. SimPowerSystems is introduced in the vehicle energy course, and reinforced with several programming-simulation exercises.

Fuel Cells

Fuel cells are introduced early in the course when discussing the Fuel Cell Series Hybrid Power train. Instruction covers basic theory, history, and current status on Fuel Cell systems for vehicle applications. No laboratory fuel cell instruction activities are available for this course.

Laboratory Activities

There are no uniquely dedicated laboratory rooms or equipment for Vehicle Energy Systems. The instruction shares existing typical digital and analog electronics labs as appropriate. The course does have access to Hampden electrical motor trainers as well as access to a passive, eddy-current dynamometer with real time control and instrumentation.

The university does not own a test vehicle for academic use. A nearby supportive automotive test facility has provided much appreciated support by lending occasional use of their on-site test vehicle for instruction that involves dynamometer loading and on-vehicle communication system testing instruction.

Electrical power laboratory instruction and testing relies on sharing the typical electrical machine laboratory facilities as well as the Hampden 1/3Hp motor trainers.

MATLAB, Simulink, and CAN Simulation

In addition to the power laboratory, a typical analog electrical laboratory is available for use in the course. Each electrical bench has a typical computer with MATLAB and MATLAB Toolboxes, Simulink, and SimPowerSystems. The same computers also have Vector CANoe software. Several MATLAB Toolboxes are installed on those computers and available for student use. Simulink SimPowerSystems and Vector CAN software is also available for classroom student use.

Figure 3: Senior Design Team and Vehicle Chassis Dynamometer and Controller

Vehicle Chassis Dynamometer

The School of Engineering and Technology does have access to a passive Chassis Vehicle Eddy-Current Dynamometer. The used dynamometer has been installed in the floor of a drive-in laboratory in the Engineering & Technology building facility. The School has also been supported by a nearby automotive vehicle testing center. That facility has loaned their "Driver Trainer Car" to the school for brief periods to run on the dynamometer as shown above.

Assessment Reports

Assessment for the current year is not available at this time. The following data represents Assessment Reports for prior offerings of the course in 2015 and 2013.

Assessment Spring 2015

1. Discuss sustainability issues for automotive transportation.
   Student Self Assessment: (Subjective) ……………...…. 83%
   Faculty Grades of Student Work: (Quantitative) …..….. 85%

   Student Comments
   - Mostly because of knowledge I gained outside of class
   - From media outlets

- I read the book and feel comfortable with this topic
- Described well in class and in text
- Good understanding of this area, came to the class and a class from sustainability and energy systems

Faculty Comments

Initial course lectures on this topic using initial chapter(s) of the Hybrid Electric Vehicle textbook.

2. Perform basic calculations involving electrical current, voltage, and power as well and speed, torque, and efficiency. Discuss and perform basic calculation for hybrid topics such as speed coupling and torque coupling of multiple motor systems.

Student Self Assessment: (Subjective) ……………..…. 89%
Faculty Grades of Student Work: (Quantitative) ….….. 85%

Student Comments

- From other classes
- Review a little from EGEE210
- Described well in class
- Motors in the lab and in class. Completed homework
- Because of other classes

Faculty Comments

- There was a very wide background of the students even though they had the prerequisites. 3 ME seniors, 1 ME Transfer, 1 ME Junior, 3 EE Sophomore / Junior
  None of the students had taken the EGEE330 ElectroMechanical Systems(Motors).

- Speed and torque coupling are essential, fundamental topics in hybrid vehicles. I presented the topic and worked through example calculations. The students then worked through meaningful, yet not complex, calculations. We used the Toyota Prius architecture and made use of an on-line simulation. www.eahart.com

3. Use MATLAB/Simulink to model electric/hybrid systems, and evaluate power, speed, torque values.

Student Self Assessment: (Subjective) ……………..…. 85%
Faculty Grades of Student Work: (Quantitative) ….….. 83%

Student Comments

- Comfortable with MATLAB, but need a lot more practice with Simulink
- Demonstrated through labs

- Completed projects in lab and MATLAB
- Matlab: yes Simulink: no

Faculty Comments

- Initial labs were used to introduce Simulink basics and calling Simulink from MATLAB.
- After initial lab activities the class worked in groups on a functional but simple simulation of an electric/hybrid vehicle where the speed and torque requirements were specified. The simulation was divided over several weeks with portions given each week.

5. Discuss the use of other technologies, such as MEMS, in vehicle systems applications.

Student Self Assessment: (Subjective) ……………..…. 79%
Faculty Grades of Student Work: (Quantitative) ….….. 60%

Student Comments

- Just started to learn about this area
- Not a lot of exposure to it
- Described well in class
- I know MEMS exists, but I know nothing more
- This was barely mentioned, but I have heard of it elsewhere
- Don't know what MEMS is

Faculty Comments

My goal was simply to introduce MEMS applications in automotive systems because they are used extensively in automotive systems and elsewhere. I completed a graduate course in MEMS at Oakland University, and wanted to inform the students of the existence of MEMS technology. I still feel that students who are drawn to vehicle systems would do well to have some awareness of this topic. Possibly this could be a paper assignment.

General Forecast of Assessment

Assessment Spring 2013

Note: EGEE365 Vehicle Instrumentation in 2013 then changed to EGNR362 Vehicle Energy Systems.

General Comments

This was the second offering of the EGEE365 Vehicle Instrumentation course. A somewhat similar Special Topics course was also offered in Spring 2007 that emphasized LabVIEW programming, and Spring 2008 that emphasized CAN programming.

The student population consisted of nine senior and junior students. Many of the students were very well prepared, and had high GPAs.

I believe all of the students were pursuing a Vehicle Systems track; however, none of students indicated that they intended to work in that area.

This offering of the course primarily focused on current topics in vehicle instrumentation and related software tools. The course emphasized software instruction and application in MATLAB, Simulink, and CANoe (CAN). A significant part of the course during this offering included reviewing documents and information on current vehicle systems topics especially those with a communication or instrumentation focus.

I was on sick leave for medical treatments 350 miles away for several weeks during the course. This was an added challenge in that a significant aspect of the course is learning new, and unique, software. I tried as best as possible to prepare items ahead for the students, but naturally problems surfaced and it was difficult to resolve student programming problems via email. The final resolution was that I ended up giving the students my software solutions and having them run and investigate them.

During my absence I maintained regular communication with the students via email. I reviewed drafts of their CAN Programming manual that they developed, assigned and critiqued short essays, answered Simulink questions and debugged some student work that students sent to me.

There is no appropriate textbook for the course. The course is somewhat similar to the PLC (Programmable Logic Controllers) class in that it is focused on industrial applications and has no traditional textbook to provide focus for the course. Like PLCs there are instructor generated basic exercises for programming assignments followed by projects that require software and hardware use and debugging of student programs or scripts.

The course content focused on vehicle network systems, electric vehicle simulation using Simulink, and CAN communication using CANoe.

MATLAB/Simulink was introduced at the beginning of the course. The students had previous experience with MATLAB, but the Simulink portion was new for them. After a few introductory Simulink activities the focus changed to developing a simple, closed-loop simulation of an electric vehicle drive train. This was a simulation that I had developed that involved determining the key equations for the electric drive train, associated speed and torque requirements, and a simple model of a battery, power converter, and electric motor.

The CAN communications involved using CANoe from Vector CANTech. This is a popular industrial software product that is used at a wide variety of vehicle systems related companies including Chrysler and Continental.

The CANoe programming involved six laboratory activities that I had prepared:

1. Introduction to the CANoe IDE using the Demo EASY
2. CANoe Basics: DataBase, Interactive Generator, Panel Editor
3. CANoe Analysis: Measurement Setup, Hardware Setup, Software Filters, Logging
4. CAPL Programming: (a C like CAN bus programming language) Event programming, CAPL Browser (IDE), CAPL Events, Panel, Basic BUS Simulation. An example would be to start logging data or stop something else when a specific CAN bus message was sent or when some parameter within a routine message exceeded preset limits.
5. CAPL Simulation
6. CAPL Application

A new approach that I included this time involved having the students write short essays on current vehicle systems or electric and hybrid vehicle topics. This seemed to go well, and helped the students to realize the new technology and variety of opportunities that exist in the work area. I also used this tool to have the students explore various types of vehicle instrumentation.

<u>Sample topics included:</u>
Autonomous Vehicles, Local Interconnect Network (LIN Bus), Flexray Bus,
Wireless vehicle applications
Ethernet vehicle applications
ISO26262 Functional Safety Standard for embedded vehicle systems
Vehicle – 2 – Vehicle and Vehicle – 2 – X communications systems
CAN ISO 7-layer topology
Other Hybrid/Electric vehicle applications including trucks and construction equipment
On Board Diagnostics
2025 CAFÉ Mileage Regulations
Fuel Cells

The students also created a project or paper and then made a presentation to the class. Sample topics included LabVIEW applications, Autonomous Vehicles, and Vehicle Vibration Analysis.

There were other specific laboratory activities that I had hoped to include this year, but it didn't work out. These include On Board Diagnostics, Calibration, and CAN target applications.

Use of Dyno and On Board Diagnostics:
Continental provided a loaner vehicle and also provided us with a partial CAN Data Base for the vehicle. This information will allow us to access some vehicle parameters over CAN via the OBD diagnostic connection. This was not tried, but should be very doable now.

ECU Calibration and Data Acquisition:
I was able to attend calibration training using CANape from Vector, and Vector donated copies of this software to LSSU. CANape is ECU Calibration software. It is somewhat like an extension or expansion of CANoe that enables CAN communication with target controllers for the purpose of calibration of internal parameters or acquiring data from the internal memory of a microcontroller via a MAP file.

This software is used extensively in the vehicle systems environment to "flash memory" much like when a car manufacturer sends the owner a recall notice to "update" code in an engine or power train controller or some other controller in your vehicle.

The software is also used to acquire data and set calibration values of power electronic motor drives and other controllers on the vehicle. Many aspects of speed, torque, efficiency, emissions, or other key factors are non-linear and some items such as hybrid motor power controllers are "calibrated" by motor control engineers using dynamometer load tests or other testing.

Simulink models are calibrated at the measured points, and then intermediate points are estimated using MATLAB/Simulink based correlation algorithms within Look-Up Tables. Advanced DSP and power electronics engineers use CANape or similar calibration software to pre-set experimentally determined points within the controller memory. Thus vehicle systems, testing, and many other engineers use CAN Calibration Protocol (CCP) or Extended XCP (with Ethernet) based systems every day.

One of my many illusive dreams is to have our own controller-based system where students can use a CAN-based approach for controller data acquisition and control applications to get test values, change amplifier gain, etc. It is completely doable in our environment and we now have the software. Now we need the controller and its map file.

Analog & Digital Topics:

Many common topics of analog and digital electronics are naturally introduced or reviewed within the course because the analog world is communicated via discrete systems, and many of the students have a minimal or no A-D background. Topics such as amplification, phase shifting, gain, dB, resolution, bit weighting, Big Endian and Little Endian, etc. need to be introduced

Signal Processing:
During this most recent offering of the course we introduced some basic EGEE280 Introduction to Signal Processing (DSP) topics including the concept of sampled data, discrete signals, data acquisition, sampling and aliasing, anti-aliasing filters, and an introduction to Finite Impulse Response filters and convolution. This was a real "eye-opening" experience for several of the students who then indicated that they wish they would have taken the course. Last year EGEE280 had three MEs, and this year there are several MEs in the course.

Grades:
Note: Actual grades show as 89% for all activities.
There are several reasons for that. First, the majority (6 out of 9) of the students were very strong academically so the overall grades were high. Also, many of the assignments represented group work with high grades.

Return on Professional Development Funds:
Last year I participated in the following Society of Automotive Engineers Training in Troy, MI, and was able to bring some of the content into EGEE365. The courses were: 1) Embedded Control Systems Design, and 2) Acquiring Data from Sensors and In-Vehicle Networks.

Analysis of Objectives

1. ***Describe general vehicle controls and instrumentation systems.***

   Student Self Assessment: …………..…. 78%
   Faculty Grades of Student Work ….….. 89%

   Student Comments : None

   Faculty Comments

   This topic was emphasized more this semester than the past, but not as much as it could have been.

2. ***Apply, design and implement testing procedures, evaluate component or system performance and control operation, and document testing outcomes.***

   Student Self Assessment: …………..…. 68%
   Faculty Grades of Student Work ….….. 89%

   Student Comments : None

   Faculty Comments

   We did very little actual testing, but did a lot of modeling and simulation.
   I expect this area to increase in the future now that we have CAN dbc file for Continental vehicle and access to CAN data via the OBD2 diagnostic connector under the steering column.

3. ***Use MATLAB/Simulink to model systems, and write scripts to analyze and plot data and discrete signals.***

   Student Self Assessment: …………..…. 73%
   Faculty Grades of Student Work ….….. 89%

   Student Comments

   - Exercises in class highlighted this.

   Faculty Comments

   The students worked through several introductory MATLAB/Simulink exercises. They then worked through a series of Simulink activities that focused on basic modeling and simulation.

The students also worked through a series of laboratory activities that focused on discrete signals, sampling and aliasing signals, FFT, and FIR filters.

4. Analyze the operation and simulation of CAN networks.

Student Self Assessment: …………..…. 71%
Faculty Grades of Student Work ….….. 89%

Student Comments

- More time would have been helpful.
- CANoe is a complex program

Faculty Comments

The students worked through three labs that I had developed from the Special Topics offering of the course. These exercises were essential to understanding CAN, and additional general CAN activities would be good. The students purchased a copy of the CANoe programming manual, and worked through CAN-based data analysis and an introduction to CAN Node Simulations.

5. Program interfaces with CAN:

Student Self Assessment: …………..…. 77%
Faculty Grades of Student Work ….….. 84%

Student Comment

Faculty Comments

The students worked through programming exercises to learn the basics of CANoe for CAN analysis and simulation.

Part 2: Discussion Question

Given a reasonable amount of time, do you feel comfortable in approaching a vehicle instrumentation or data acquisition problem that involves the use of CAN?
Yes
Yes, I believe I have a firm grasp of the fundamental concepts of CAN.
Kind of difficult with the amount of time the professor was away.
Given adequate time and resources (manual, examples, etc.), I feel that I could solve vehicle instrumentation problems using CAN.

Summary:

This paper reflects a portion of the content of a course that is meant to help students to think and learn and demonstrate what they have learned in the area of vehicle systems engineering. Hopefully in the process those who learned about vehicle energy systems will in turn serve and teach others.

It is a precious privilege to be able to teach and encourage students and not taken lightly. And even more of a privilege to realize what they teach us in the process. This paper is but a small example of what I have learned in the process of allowing students to teach me. As I encourage them, they in turn encourage and humble me. Never take teaching for granted.

References:

1. Hybrid and Electric Vehicles, Principles and Application with Practical Perspectives. Mi, Masrur, and Gao. Wiley 2011. ISBN: 978-0-74773-5
2. Electric and Hybrid Vehicles, Design Fundamentals 2nd Ed. Husain. Taylor and Francis 2010. ISBN: 978-1-4398-1175-7
3. A Comprehensible Guide to Controller Area Network 2nd Edition, Wilfred Voss, ISBN-13:978-0976511601. http://www.copperhillmedia.com
4. CAN-Based Instrumentation with CANoe and MATLAB, ASEE NCS Conference 2011, McDonald.
5. Data Acquisition in a Vehicle Instrumentation Course. 2010 ASEE Annual Conference & Exposition, Louisville, Kentucky. McDonald, https://peer.asee.org/16278
6. Laboratory Learning Experiences Vehicle Engineering. SAE 2010 World Congress
7. A Comprehensible Guide to Controller Area Network 2nd Edition, Wilfred Voss, ISBN-13:978-0976511601. http://www.copperhillmedia.com
8. Simulation Learning Experiences in Energy Conversion with Simulink and SimPowerSystems, ASEE Annual Conference, McDonald, 2006, Chicago.