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Incorporating Sustainable Automotive and Energy Design into the Engineering Curriculum using Remote Control Cars*

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The Engineering Education and Centers wing of the National Science Foundation has undertaken the task of re-structuring engineering education. The objective is to make it more effective, quality conscious, flexible, simpler and less expensive. A novel capstone design project at the University of Kansas addresses these concepts using Remote Control (RC) cars. RC cars are an effective teaching tool as they help to focus the analysis of the ideas while increasing the relevance to current social topics. It produces better engineers by creating a curriculum-wide methodology that merges theory with practice, generating better quality designs. The flexibility of the program is evident in the six different designs created in the first year alone using varying levels of technology. Small-scale building is inherently simpler as parts are easier to manufacture and mistakes can be readily eliminated and components remade. Finally, at around $1200 per 1/8th scale car, the costs of the program are significantly reduced, making the project feasible for all universities, community colleges and even high schools of various sizes.

Keywords: sustainability; automotive; capstone; mechanical; energy

1. Introduction

Engineering is fun and relevant. Students sitting in engineering classes often lose sight of these facts as lecture after lecture labors on. In fact, idealistic students who see engineering as an avenue for change with respect to society often become discouraged by the seemingly endless drudgery of courses that appear disconnected from one another [1]. As a result, only 40% to 60% of new engineering students persevere to obtain an engineering degree [2, 3] with one study illustrating that 98% of students cite poor teaching as a major reason for their departure [4]. Therefore, it is up to the instructor to break up this monotony by incorporating new techniques in the classroom along with projects aimed at revitalizing the enthusiasm of the students.

It has been said that scientific and engineering knowledge doubles every ten years [5]. The standard length of engineering education remains at only four years before the student begins practicing in the field. This deviates from other professions, like law or medicine, which require about twice the length of training in order to perform in their respective fields [6]. What this means for engineering educators is that the curriculum needs to be continually revised, taking into account new material while still including the past knowledge and without the added benefit of more time. As a result, engineering education in general has to refocus its plan for the future by making use of all pertinent forms of technologies available to the practicing engineer today. As a guideline, faculty can look towards the Engineering Education and Centers (EEC) wing of the National Science Foundation (NSF). They have undertaken the task of re-structuring engineering education in order to make it more effective, quality conscious, flexible, simpler and less expensive [2, 7–9]. From this understanding of the needs of a curriculum, the main author began a new senior design project at the University of Kansas (KU) in the Department of Mechanical Engineering that addresses these ideas through the fabrication of 1/8th scale Remote Control (RC) cars and a green energy infrastructure as their capstone design project.

To provide some context, upon starting at KU, the main author wanted to start a project that incorporated his enthusiasm for the automotive field but from a different perspective from traditional vehicular programs. In particular, the United States automotive industry has undergone a sweeping paradigm shift in philosophy towards fuel economy and away from performance [10–15]. The recent surge in fuel costs [16–18] has forced everyone to become more aware of the impact of miles per gallon on their finances. While fuel costs have dropped from a peak of over $4.00 per gallon, some believe that a fundamental change in the mindset of manufacturers and customers has occurred [19]. This is evident in a General Motors'

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survey that indicates that nearly 80% of Americans who plan on buying or leasing a car would select a 'greener' car over a more aesthetically pleasing alternative [20]. However, for years the auto industry has touted engine power over fuel economy as little consumer or regulatory pressure was placed on their practices as indicated by the decreasing fuel economy values across platforms [21]. As a result, this shortsightedness has led to significant troubles, as sustainable practices were not in place to recover from an inevitable shift in demand [22]. This is particularly disconcerting for the industry given the fuel economy and greenhouse gas standards appearing on the horizon [23, 24].

The change in priorities must also occur within a university curriculum, as the traditional view of 'gearhead' students going into the automotive field must be replaced with a reflection of the diversity of modern society [2, 7]. Of particular note, discussions with under-represented students indicate that the perception of automotive engineering needs enhancement with respect to energy, efficiency and the environment. This is where the previous familiarity of the main author working within the automotive sector plays a vital role by being able to relate actual experience of how most vehicular engineering occurs through simulations and modeling activities instead of in a garage setting. These models provide a powerful resource that can significantly advance the science of the field [25].

Upon starting this design project, the faculty advisor met with the students and defined a sustainable architecture as the approach to the project. The student's definition of sustainability draws from others mentioned in the literature [26–28] and illustrates the application of engineering techniques to solving real-world problems by holistically approaching the situation from five vectors of success: education, energy, environment, economics and ethics. Each of these concepts individually addresses specific aspects of sustainability, shaped by the confluence of the ideas of people, planet and prosperity. Moreover, it is through the multi-leveled application of the vectors of success that the students have developed the means to face the challenges of a sustainable approach to automobiles and the energy infrastructure.

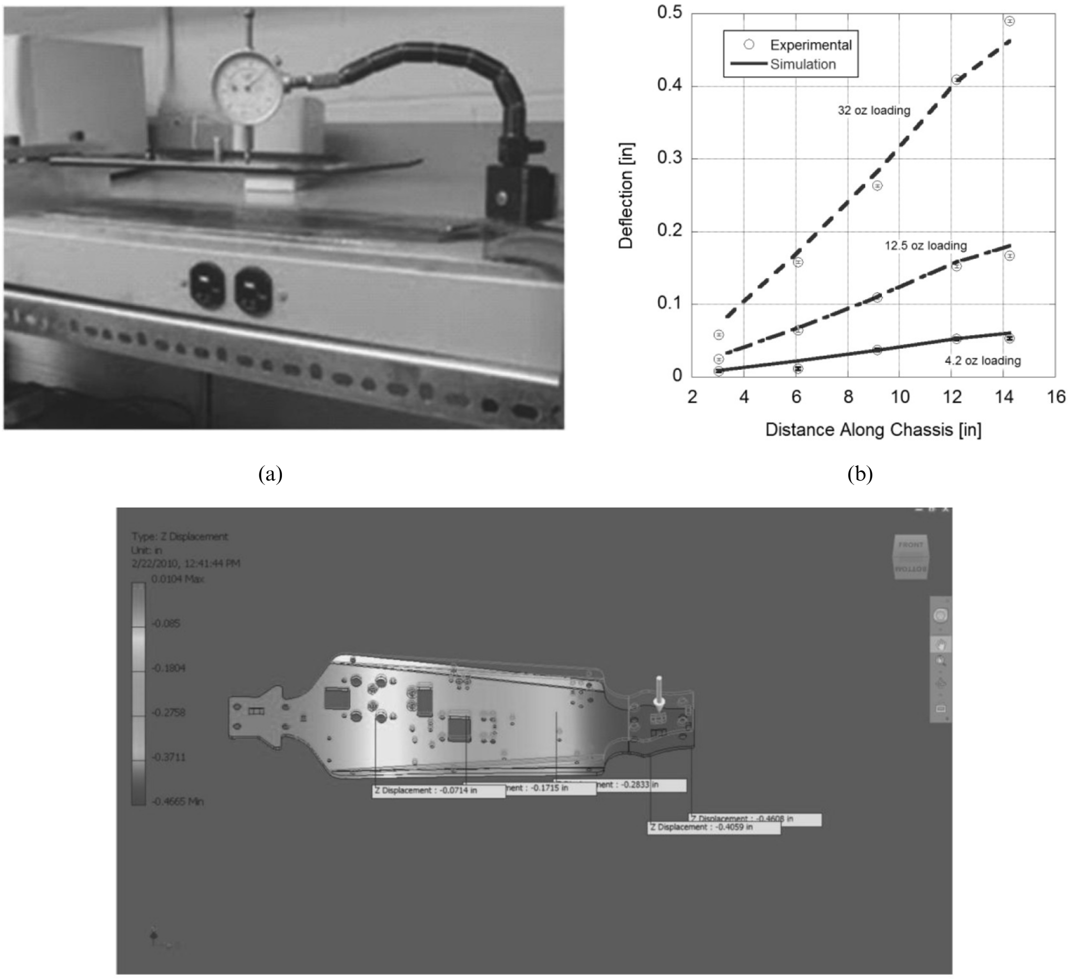
This idea of an active learning environment and a focus on sustainability is not a new concept as previous publications have elucidated [29–32]. The goal of setting a sustainable focus provides the students with a methodology of making the right decisions based on more than singular goals [29]. It redesigns the educational experience, presenting the students with an examination of the positives and negatives of each choice [32]. By incorporating an active learning pedagogy with this focus, students become more engaged in the learning process, so making the experience more effective [30, 31]. Hence, the work presented here illustrates a convergence of these ideas into a capstone design project expanding classroom examples into a year-long effort. This instructs students how to implement sustainability from the start of a project through to its completion. Moreover, since the students decide on their own RC car objectives, they learn how to justify their decisions to people who have a wide range of differing opinions.

This paper describes the overall objectives of the RC cars, how they fit into these sustainable vectors and the curriculum as a whole, both inside and outside of the main author's home department and its subsequent synergy with the NSF EEC. This culminates in a description of the concept vehicles built by the students in the first year of the program, briefly touching on each of the five sustainability facets in their design. Finally, this work ends in a discussion of the lessons learned, along with the next steps of the program.

2. Educational sustainability

As discussed in the introduction, students often feel that the courses that they take are disconnected from one another. Without some unification, students may become disinterested and feel that they are lost in the shuffle. Ideally, a capstone design project brings all of these previous classes together to a common focus. Without proper context and guidance by instructors, students may never see this connection. In addition, faculty in the early curriculum courses must illustrate to students how the exercises in these classes will lead to a better design in their capstone project. One team leader cites seeing some attempt to unify the concepts taught throughout prior core classes in a mock design project (ME 501). However, without hands-on design, construction, and testing the project did not provide an accurate look at the design process because the success or failure of the student's design was purely hypothetical.

Often in a design project, students spend countless hours designing components within a commercial Computer Aided Design (CAD) program. Moreover, they perform virtual experiments to illustrate the stress on these components and their deflection under different loadings. Given the main author's modeling background [33], without experimental validation, the results from these simulations cannot be trusted. Too often, students treat these programs as a black box, believing what the simulation tells them and they miss the fact that models contain assumptions and are not exact [34–36]. A simple, practical test of a CAD part helps



(a) (b)

(c)

Fig. 1. (a) Experimental, (b) comparison results and (c) FEM simulation of chassis loading.

demonstrate to students possible errors in their drawing and better modeling practices moving forward. Proper engineering using computers involves an understanding of the theory behind the software and its correct implementation, along with a knowledge of the accuracy of the results.

Using RC cars allows the educator to perform simple, inexpensive tests of the theory, not only in the capstone project but also in previous classes. For example, the main author requires the students to create a CAD model of a previously built chassis, perform a cantilever type loading experiment and compare model results to this experiment while explaining the fundamentals behind the software program. While a cantilever type loading is not representative of the actual loading on the RC car, or on an actual full sized vehicle, this simple test provides an effective way of getting students to understand the software program and treat it less like a black box. After proof of reasonable validation between the model and the experiment, as seen in Fig. 1, the faculty member is now confident that the student is able to use the CAD software correctly in designing parts for his or her own vehicle.

From one student author's internship experience, a common situation that students encountered was that there is some disparity in the experimental versus simulated results as Fig. 1 demonstrates. It is up to the engineer to determine why this disparity exists. Moreover, it is crucial that the engineer understands the theory and assumptions behind the simulation in order to explain the discrepancy. Hence, by bringing this into the capstone design project through a simple loading experiment, the quality of the student leaving the project is improved.

RC cars also allow for the teaching of extrapolation techniques and can illustrate to the students how to make well educated guesses based on theory, experimentation and error analysis. In the capstone project, students can design any style of car. However, before they make it, they must perform a wind

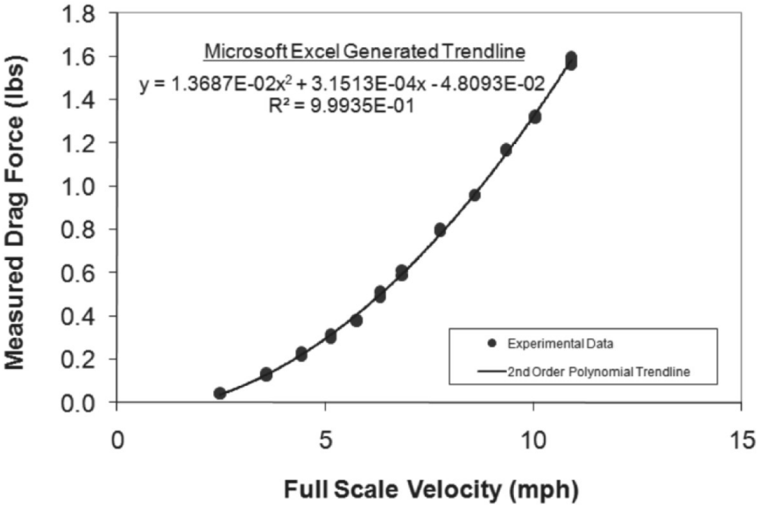


Fig. 2. Drag force for 1/10th scale BMW M3 resin model in University of Kansas wind tunnel.

tunnel experiment on a resin body of known coefficient of drag (CD). At KU, students have access to a wind tunnel with a maximum speed of 125 miles per hour. The instructor provides funds for the students to purchase any size scale model (1/8, 1/10, 1/12) with a similar intended design for testing in the wind tunnel. Other scales are initially allowed, based on the availability of pre-fabricated models with known CD values for purchase on-line. This allows the students to obtain experience with the wind tunnel, validate to the instructor proper data collection while demonstrating the fundamentals of drag, Reynolds number scaling theory and data analysis. Figure 1 provides the results of one team's experiments for a purchased 1/10th scale model with the x-axis labeled appropriately via scaling theory, often forgotten by the students. Since the wind tunnel represents a realistic on-road drag of only 12.5 miles per hour for this example, students can fit the drag force data versus velocity using a 2nd order polynomial in order to extrapolate the information to higher vehicle speeds. Essentially, students create a simple model of drag from experimental data. This gives a perspective of designing beyond what the experimentation will allow, as long as the students understand that what they are doing amounts to a well educated guess. This translates well into an industry environment, as often there is not enough information available, requiring the worker to extrapolate his or her research and knowledge.

In essence, the previous two examples illustrate that the RC Car capstone design project builds on the knowledge gained in previous classes and makes students relate theory to practice, a method of quality control. A better approach moving forward is to build these simple examples, like chassis deflection and Reynolds number scaling theory, into the previous courses so that the quality control occurs before the capstone design project is started. This requires coordination among all faculty, inside and outside the advisor's main department. This task is underway at KU with the main author working with other faculty in order to determine the appropriate examples to include based on the courses taught. How this may work is indicated in Appendix 1, Table A1 (at the end of the document) by analyzing a parallel hybrid RC car that was built by the students in the last academic year. The components of this vehicle and the efforts of the students can be broken down as follows:

1. Floorpan type chassis
2. 'Nitro' two-stroke internal combustion engine
3. Brushless electric motor
4. Lithium battery pack
5. Double wishbone suspension
6. Electronic speed controller
7. Truck body design
8. Proposal writing, presentations and reports
9. Theoretical models.

A systematic incorporation of examples in early courses will prepare students for the capstone project, while facilitating a common thread throughout all of their classes. These examples can be flexible in terms of outcomes, as long as the faculty member demonstrates a thread of continuity with a senior level capstone project.

Additionally, the use of RC vehicles increases the interdisciplinary nature of the program by creating independent projects with a common purpose. Previous experience, as a student and as a faculty member, illustrates that working in parallel on a common project across disciplines is fraught with issues. Students from one discipline typically only listen to the faculty member of that discipline. Moreover, coordinating time on the same design is subject to different deadlines, course structure, objectives and student personalities. Team leaders have a difficult enough time getting their own peers to perform the work; hence, management across departmental lines between peers is extremely demanding. Ideally, students should work together in an interdisciplinary manner in early classes and on the same capstone design project as that is what occurs in an industrial setting. However, this requires a wholesale change in the departmental structure system and is beyond the scope of this paper.

Instead, what RC vehicles allow as a design project is a phasing of interdisciplinary education that alleviates the demands on the faculty and students. For example, a group of Electrical Engineering and Computer Science (EECS) students at KU implemented a regenerative braking design on an RC car platform independent of the capstone project in ME. While working independently, their design will eventually be employed in the cars built by the ME students after the EECS students test, debug and validate their tactics. Additionally, this provides a quality control of technology into the program, a tactic common to commercial design development. Through experimentation and modeling independently, ideas can be refined and honed before the time required to merge the concepts, making the program more efficient both from time and cost perspectives.

Perhaps most important, RC vehicles provide a perfect medium for competition among departments and inclusion of K-12 students. National competitions always stimulate the enthusiasm of the student, but some come at the cost of neglecting other classes. Discussions with engineering faculty, here and at other universities, have indicated that the need to finish first in these competitions has caused students to miss graduation dates and make poor decisions regarding their coursework. Creating an in-house competitive environment would increase the excitement factor of engineering while remaining cognizant of the student's requirements for completing their other academic duties.

As discussed in *Educating the Engineer of 2020*, 'Engineering schools should lend their energies to a national effort to improve math, science, and engineering education at the K-12 level' [2]. This integration of K-12 education is inherently feasible because RC vehicle builds of different difficulties can be created for younger students. This allows a direct linkage between younger and older students, so helping foster the development of future engineers. This integration began this past year as the ME capstone design students held a gravity-powered race for K-12 students as part of the School of Engineering's Exposition. This led to the ME students gaining first place for their efforts and teaching a number of younger students about sustainable engineering practices. This upcoming academic year will involve the gravity-powered race again, along with an extension into battery-powered vehicles to increase the level of difficulty for older students. For these competitions, K-12 students will need to provide an engineering analysis of their vehicles involving concepts such as kinetic energy and power for the gravity and battery powered competitions respectively.

3. Energy sustainability

Automobiles use a large amount of energy: not only the chemical energy contained in the fuel, but also the embodied energy contained in the transport of this fuel. Hence, any vehicular program moving forward must be cognizant of the place of the automobile in the larger scope of energy infrastructure in the United States. As a result, the faculty advisor looked toward the Department of Energy's (DoE) Strategic Approach to Transportation Energy Security and the National Renewable Energy Laboratory's (NREL) Vehicle Design Progression for Sustainable Development [37, 38] as a way of laying the path forward for the capstone design program. These entities indicate the prevalence of a large number of vehicle power plants (hybrid vehicles, electric vehicles, fuel cells) in the future using renewable fuels and electricity. Moreover, changes to the energy infrastructure will occur as evidenced by the President's Solar America Initiative, which seeks to make solar power cost-competitive with conventional forms of electricity by 2015 [39]. Finally, faculty must continually adapt the curriculum according to any shift in industrial opportunities in order to remain an effective teaching tool for national job growth. This is discussed in Innovate America where the Council on Competitiveness points toward the need for quick adaptations to new opportunities in the energy and fuel fields [40].

What is unique about RC cars is that they allow for a relatively simple shift to different prospects on a yearly basis in order to match the industry without a large investment in infrastructure and equipment. Every power plant, even gas turbines, is available on a small scale along with a wide variety of alternative and renewable fuels. Moreover, incorporation of solar and wind turbine technologies as part of the energy infrastructure is feasible on this scale. The students can even construct these components in order to help further merge the understanding of theory to a practical device as part of quality con-

(a) (b)

Fig. 3. (a) Biodiesel blend for RC car internal combustion engines and (b) test platform.

trol. This flexibility in the energy field through different RC power plants is evident in two of the six student vehicles built in the past year.

One team built a parallel hybrid vehicle using a small two-stroke Internal Combustion (IC) engine and a brushless electric motor as representative of what is available in the marketplace, e.g. similar to a Toyota Prius. However, in their build, they were required to use a biofuel in the small IC engine following from DoE and NREL's objectives. This required an understanding of fuels learned in a previous class (ME 636 indicated in Table A1), and they were able to suggest a biofuel consisting of 40% biodiesel, 40% n-heptane and 20% castor oil. The biodiesel was made from used cooking oil converted in a Chemical and Petroleum Engineering (CPE) student project on campus and served as the main fuel [41]. N-heptane was used as a fuel enhancer because of its flammability and volatile properties as evidenced by research of the students and the first author [42]. This fuel enhancer is required because these small two-stroke engines are carbureted. Castor oil served as the two-stroke engine lubricant to reduce the friction of the engine. The students had to test blends of these components of this biofuel for viability, as shown in Fig. 3, before implementation in the actual RC vehicle. This is analogous to current biodiesel research through testing blends in production diesel engines. From this build, students were able to learn the concepts behind hybrid vehicles and biofuels using the RC car approach.

Another team built a fuel cell series hybrid vehicle using a $ReNi_5$ metal hydride storage tank. Throughout their build, they encountered challenges regarding a proper matching of electric motor to fuel cell power and storage of hydrogen in the metal hydride tank. In particular, since this tank required a pressure of more than 8 bar to allow for the flow of hydrogen into the tank, the students had to develop a system in order to accomplish this task. They eventually built a small-scale electrolysis system that filled a large syringe with hydrogen. From the force applied on the plunger over the small area exiting the syringe, they were able to provide sufficient pressure to fill the tank. Moreover, by including a one-way pressure valve and the architecture of a series hybrid platform, they could run the vehicle motor off the fuel cell with any excess power charging the accompanying battery pack. From this build, these students were able to explore future technologies, part of DoE and NREL's objectives, without significant expenditure and with a minimized complexity of components. They investigated the issues involved with hydrogen storage and discussed in their final report what is needed in order to make a nationwide hydrogen infrastructure feasible.

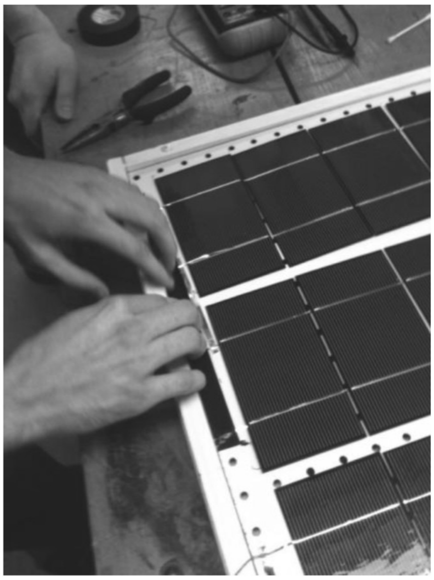
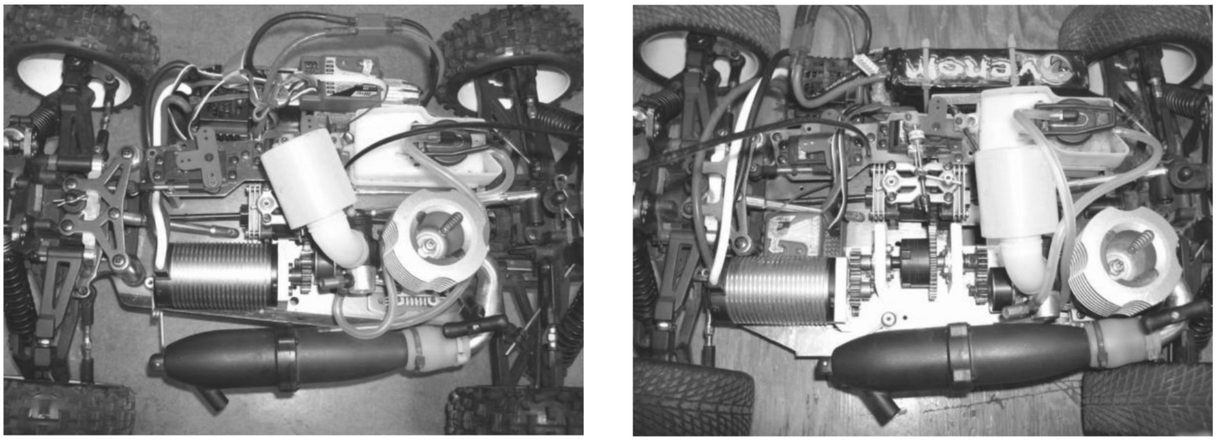


Fig. 4. Capstone design student building a solar panel for charging RC car batteries.



(a) (b)

Fig. 5. (a) Parallel hybrid iteration No. 1 direct connection between spur gears of engine and electric motor and (b) iteration No. 2 with planetary differential to promote synergy between engine and motor.

These two builds demonstrate completely different energy drivetrains targeting distinct levels of the DoE and NREL platforms. Moreover, all teams were required to collaborate on building their own solar panels in order to charge the batteries included in all RC vehicles as shown in Fig. 4. This provided a relatively simple incorporation of renewable energy infrastructure into the program. This was all accomplished in one academic year because of the flexibility of the RC car platform. In fact, this scale allowed the parallel hybrid team to build two iterations of their drivetrain shown in Fig. 5. This successive iteration in one year is not feasible on a large scale given cost, materials and student time. Hence, this is an extremely effective method of getting students working on multiple facets of the energy field.

Finally, RC cars allow for the exploration of advanced energy technologies like the smart electrical grid. This is important as the batteries in plug-in hybrid and electric vehicles can provide five distinct benefits in the future: a lowering of greenhouse-gas emissions, an improvement in urban air quality, a saving of consumers' money, a bolstering of power-grid reliability and a reduction in oil imports [43]. The government is encouraging utilities to upgrade capabilities, so allowing electric appliances to communicate with the grid and charge themselves based on real-time power prices. In fact, an electric vehicle can become a moving power plant, useful for times of high peak demand and for storage of energy from non-constant energy sources such as wind turbines. However, little background exists within the engineering curriculum to teach students how to monitor and adapt to this communication. As a result of this design project, the main author was able to secure a grant from the EPA P3 Program to develop a demonstration smart grid using the student-built solar panel and the RC car battery packs. In this upcoming academic year, the students will build a system that can pull energy from the RC packs and put it back onto a simulated grid. This further illustrates that all current and future energy topics are feasible because of the flexibility of the RC car platform.

4. Environmental sustainability

Environmental Sustainability focuses on how people fit into the varying ecosystems of the world. Recent movies have piqued public awareness of the possible effects of the excessive use of fossil fuels, while erratic energy costs are changing where consumers choose to spend their money. This has led to an increased demand for hybrid and alternative fuel vehicles that has tempered only recently [44, 45]. In order to be responsive, any capstone design project involving automobiles and their associated energy infrastructure must include the impact of student design decisions on the environment.

What the main author found is that by allowing for innovation on a small scale, students actively consider the environmental footprint of their RC car design. This is seen through the choice of eco-friendly fuels that were not originally considered as part of the project, like hydrogen [46], in their final product. Moreover, the teams building Electric Vehicles (EVs) often chose the newest batteries with the highest power density, $LiFePO_4$ and $LiCoO_2$, for their drivetrain, with all teams mentioning a reduced dependency on petroleum oil factoring into their choice of battery. While the cost of these batteries on a large-scale are prohibitive, on a small-scale it is not expensive for the students to build and test a battery pack involving the latest technology. For example, one team opted to implement $LiCoO_2$ batteries with the highest discharge rating in amperes of any battery in the world. This demonstrates that RC cars are an effective method in enabling student to learn about the latest technologies intended to reduce the environmental signature of automobiles.

A side benefit was the ingenuity of the students to use as much recycled material as possible. As part of the project, students are required to create a budget for their vehicle in a proposal for funds; this is described in more detail in the next section. Student prodding resulted in recycled or scrap items being considered 'free' items; hence, students actively searched through the scrap material in the university machine shop and called local businesses to see what extraneous material was available. Because the vehicle builds are relatively small, significant material is available for the students to fabricate a vehicle from scraps that are just lying around various places. This further reduced the environmental impact, along with saving the fuel and energy costs to transport these materials elsewhere for recycling. This would not be feasible for a traditional size automobile, as not enough leftover material exists; however, on a small scale it reinforces the need for recycling to reduce our impact on landfills and energy usage.

Furthermore, in their final reports teams often discussed the ramifications of their decisions on the environment when it comes to manufacturing, worker health and recyclability. They became more cognizant of the influence of their decisions on the environment and strove for more sustainable designs. In addition, the flexibility allowed through RC cars allowed for relatively simple incorporation of a student-built solar panel with enough power to charge all of the batteries in the different designs. This further reduced the environmental impact of their designs and helped to stimulate the discussion about how renewable energy technologies will factor into the energy infrastructure of the 21st century. As illustrated in this section, students actively assessed the environmental impact of their vehicular designs resulting in quality-designing practices that were beyond the typical vehicle competitions that mainly targeted speed [47] or efficiency [48].

5. Economic sustainability

The support of energy markets directs this program towards Economic Sustainability, which is the union of people and prosperity [49]. This design project facilitates the Energy Technology Revolution that will be increasingly important within the next few decades. As the Information Technology boom recedes and the financial markets are in recession, the Energy Technology Revolution may become the driving force for a new stable economy by building infrastructure, providing jobs and producing the goods and services required in the 21st century global economic landscape. This idea is championed by President Obama as part of his Clean Energy Economy initiative [50]. Hence, by educating students in the renewable energy field, it supports job growth in this area, thereby increasing local and, in turn, national economic sustainability.

Therefore, it is important for students to work with the latest technological advancements in the disciplines of renewable energy and alternative fuels; however, this is not always feasible on a large scale. Note, for example, news articles illustrating that students at MIT spent $243 000 on building their solar energy racer [51] and students at Sakarya University spent $170 000 on building a fuel cell vehicle that competed in the Shell Eco-Marathon [52]. This is not an economically sustainable model of production without a large endowment and significant donations by alumni. In the case of smaller schools without such resources at hand, this model of collaborative student projects is unfeasible. However, RC vehicles allow for a considerable reduction in cost because of the relative scale of components, while also increasing the level of technology of the program. For example, brushless motors are priced at around $100 and the fuel cell that was used cost $700 with its metal hydride tank costing only $150. Newer technologies are often more prevalent on a smaller scale because of the relative cost of implementation. This makes the use of RC vehicles an effective method for students to implement and test future concepts before they are even available on the large scale.

To further add to the economic sustainability of the program and ensure that the students research and choose their components wisely, the first semester of the project is devoted to proposal writing and creating a budget with justification. This involves research into different materials and components with the students developing tables of rankings in order to defend their decisions. This gives the students a proper insight into engineering in a corporate setting where budgets are limited, especially given the current climate. Of importance, feedback by the faculty advisor on a number of groups caused them to cut their budgets significantly, with one group halving their original proposal value. The result is that the six RC car builds, described later, totaled around $7000. Given the level of technology of the program, this is a small cost to accomplish such a level of sophistication. Moreover, the flexibility allowed through the RC car approach resulted in six unique vehicles at this relatively low cost; rather than one kind of vehicle technology costing approximately 10 times more.

To help aid in funding of the program, part of the student requirements were to solicit sponsorship for their unique vehicles. Over the length of the academic year, the main author required each student to contact 30 unique companies looking for funds to help aid their build. The students were not required to obtain any funds, just merely make an attempt; however, any monies received or in-kind donations were not considered part of the budget paid for by the main author. Hence, the students could use solicited funds to enhance their concept. This provided an incentive for the students to contact companies and learn how to convey their goals to persons unfamiliar with the program. Many students indicated that this interaction with industry enabled a growth in their communicative skills and raised their self-confidence. Moreover, experts in the field helped facilitate improvement to the designs. For example, a team currently building a scale semi-truck is working with industry representatives in order to provide a concept that helps address the large issue of air drag that these semi-trucks encounter.

Finally, students are now afforded the opportunity to try and fail with reduced ramifications. Because costs are relatively moderate, students can push the boundaries of design to the physical limits of the technology instead of taking a conservative approach. Often, students learn more by failing than by succeeding and the RC approach provides the ultimate teaching flexibility in this manner. For example, upon discovering that a fuel cell alone did not provide a sufficiently strong current to power the chosen electric motor, one team incorporated a hybrid drivetrain in order to produce a running vehicle. This resulted in a hydrogen–electric series hybrid vehicle, a configuration that had been previously overlooked. After a short break-in period, the fuel cell did manage to power the vehicle alone, but the team left the series hybrid configuration as an option in the design for added versatility and performance.

Another example involved the parallel hybrid team who designed parts that had to be custom machined. In order to save money and obtain experience, the students performed the machining themselves; it typically took about five tries before they achieved success. They mentioned that they had to learn about the machines while they were making the parts, adding to the capabilities of the students as they leave the university. Moreover, the one-way bearings that they incorporated in their design broke two weeks before the car was due for completion. On the full scale, this would have complicated finishing in time, but the parts were so small and cheap that it was easy to fix the problem.

These examples illustrate the idea proposed by Sitkin, that encountering failure as a precursor to success is an essential part of the learning process [53]. This provides an effective quality control of the design process with only a small loss in time when catastrophe strikes. Moreover, testing components to the point of failure often indicates improvements that are needed in order to continue refinement on the technology.

6. Ethical sustainability

Ethical Sustainability looks to place design decisions in the larger social context so engineers can understand the wide-ranging impact of their decisions. For example, one argument under discussion is the ‘food for fuel’ concept of biofuels with respect to the next generation of vehicles [54]. Governments are weighing the social requirements for cheap, eco-friendly fuels against the idea of creating these fuels out of starch or protein rich foods. Incorporation of this concept and others into this project is intrinsic through the interdisciplinary Educational Sustainability focus described earlier. Having CPE students interact with ME students fosters the discussion of the food for fuel argument involving multiple perspectives. As a result, the faculty advisor requires students to defend their design decisions in the larger context and illustrate a sustainable approach to the vehicle and energy industry that makes ethical sense. This will help engineers to develop new technologies to address the problems faced by society.

To further encourage the ethical sustainability discussion, students are required to choose a market segment where they would theoretically sell a larger version of their car. This forces the students to analyze how their design decisions would influence the price of the vehicle. This is important as newer, more efficient and powerful technologies will cost more, as evidenced by the cost of a Chevy Volt and Nissan Leaf [55]. Hence, if students add all of the components that they desire from a singular standpoint (fast, cool, efficient), the cost of their design increases. Then, the main author posed ethical questions through discussions, such as a family living on the fringes of poverty that cannot afford an expensive alternatively fueled or designed vehicle: Do they need an ultra-high fuel economy vehicle to reduce their yearly fuel costs or a cheaper, slightly less efficient version? Through discussions and the generated data in the program, faculty can ask all of the same energy questions present in society and begin to have students understand the impact of their decisions. This resulted in some teams picking less powerful motors and batteries, making a conscious effort to consider the bigger picture of the vehicle in society.

Moreover, as illustrated by the publicity gathered as part of the project, students are being quizzed about these questions beyond the classroom setting. Having questions asked by news and print reporters causes them to consider opinions that differ from their own along with how their decisions play out in the court of public opinion. Their interaction with the public, when promoting the program or asking for donations, forced students to defend their choices as it required them to be aware of a myriad of societal issues. This facilitates the aim of producing well-rounded engineers leaving the university.

7. First year designs

In this section, each team leader describes the concept behind their vehicle (Fig. 6) along with how it addresses sustainable aspects.

Team Redline was particularly concerned with creating a fast and efficient vehicle design. Most apprehension regarding current hybrid and electric vehicle technology has been about a lack of power, speed and high cost. By building a highly efficient and lightweight vehicle, Team Redline reduced these misconceptions. The final vehicle design possessed a scaled power to weight ratio unavailable in any commercial sports car. The instantaneous torque proved to exceed the ability of the conventional drive train components to transfer the energy into usable work. By using a more modern drive by wire design, the electric powertrain vastly reduced the amount of moving mechanical linkages in the system. This characteristic greatly reduces regular maintenance costs while improving the overall lifespan of the vehicle's drive train. While an electric vehicle produces less emissions than a conventional IC engine [56], the current electric grid technology would struggle to meet the energy demands of

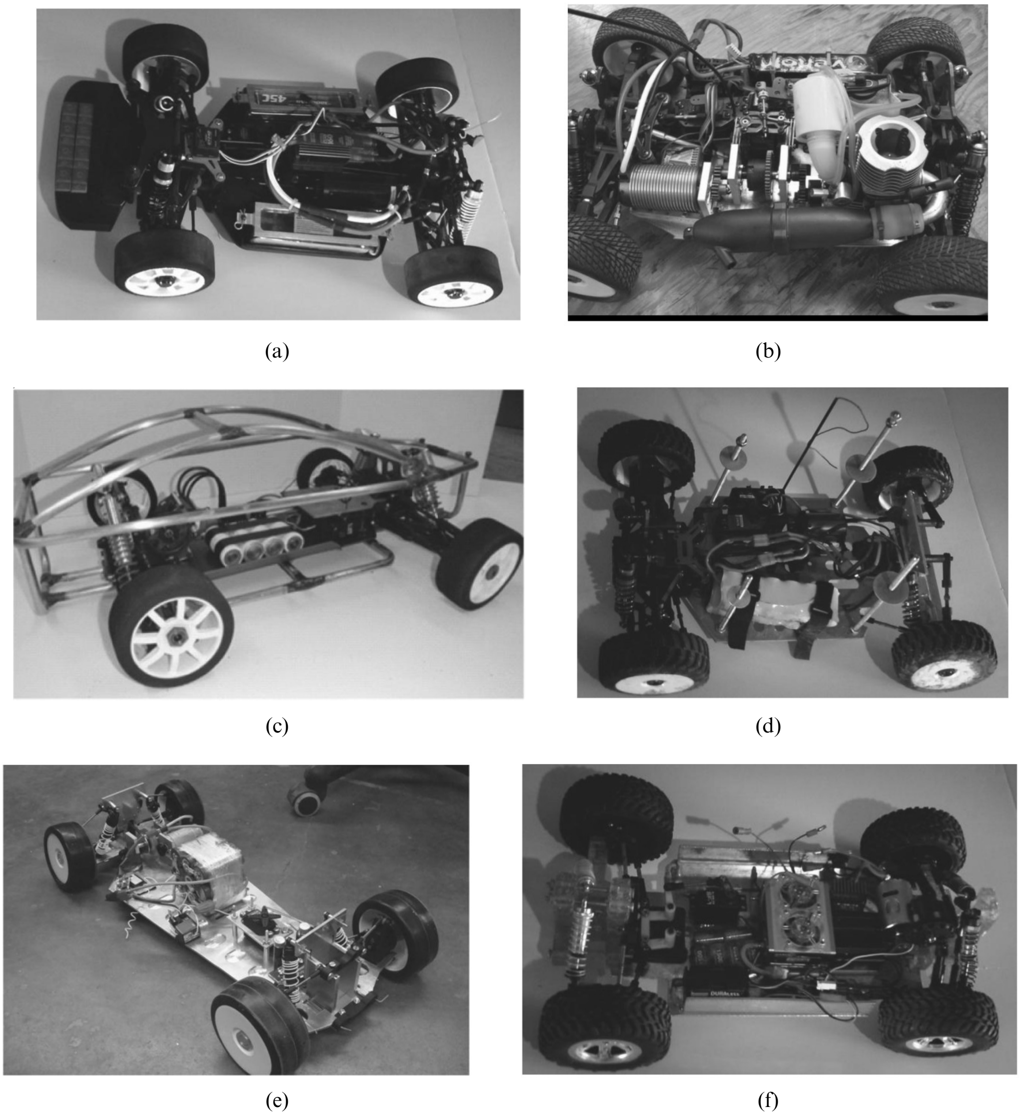

(a) (b) (c) (d) (e) (f)

Fig. 6. 1/8th scale team vehicles: (a) Redline, (b) Slayer, (c) AMP, (d) CranoFran, (e) Electric Slide and (f) CellMates.

numerous electric plug-in vehicles. To remain grid conscience the team designed and built a solar filling station. This station uses free energy to eliminate strain on the grid, resulting in an electric vehicle with effectively zero tailpipe emissions. While many of the parameters and components used in the design may not directly scale to a full-scale vehicle, the team believes the power and performance of a full-scale electric powertrain would far exceed the ability of even the best IC counterparts. The concept proved that a desirable sports car could be built with very few limitations while still meeting every component of sustainability.

For Team CellMates, building a fuel cell vehicle was exceptionally difficult for the same reason that is was rewarding: it is a new and novel technology. Building on the 1/8th scale allowed the students to explore ideas such as a fuel cell with metal hydride storage that would not be cost effective on a full scale, enhancing the economic sustainability aspect of the design. These otherwise unaffordable resources allowed the vehicle to run on hydrogen and oxygen produced renewably from solar power, giving a vehicle with no harmful emissions while remaining completely carbon neutral wheel-to-well. Because ultimately only water and sunlight are needed to power the car, it can be used wherever water is available, making it more energy independent and ethical than a vehicle that is dependent on fossil fuels. Because many aspects of the design relied upon still-experimental technology, the students were forced to innovate and apply prior engineering knowledge, as well as collaborate with professionals and academics across other technical fields, to overcome the challenges of building their vehicles. This not only provided the knowledge directly gained from building the car itself, but taught critical thinking, problem solving and interdisciplinary cooperation.

Team Electric Slide constructed an electric RC car capable of a 30 mile driving distance in simulation of a full-scale electric vehicle that is efficient as well as relatively inexpensive. To aid in the affordability of the vehicle, the vast majority of the parts used were manufactured by hand. The goal of the chassis was to reduce complexity during construction of the vehicle, while the body aimed for a low frontal area and coefficient of drag. The suspension system provides comfort and control for the driver. The driveline system sought to maintain simplicity while enabling a high cruising range. A zero emission solar fueling station to charge the electric drivetrain increased the sustainability facet of the vehicle. This eco-friendly and abundant energy source helped make this electric vehicle a viable and sustainable option for the future American consumer. Designing and manufacturing many of the components from scratch gave the team a better understanding of assembly and component usage facilitating the learning process.

Team Slayer's final design incorporated a parallel hybrid drive system along with the ability to operate on various biodiesel blends. The parallel hybrid technology used a custom designed, differential drive system, which allowed the IC engine and the electric motor to run independently or simultaneously. CAD and FEA were used in component design, along with IC engines (ME 636), fluids (ME 510), and mechanisms (ME 420) in design and kinematic analysis, thus promoting the educational aspect of sustainability. Economically, the team was able to incorporate two separate driveline design iterations along with the biodiesel concept while still keeping the budget under $1000. The team accomplished this primarily through sponsor contacts. Typically, sponsors are willing to donate to this project because not only is it interesting to them, but it also promotes their product, which again illustrates economic sustainability. Additionally, Team Slayer actively sought out recycled components from scrap metal piles, previous toys, and older RC models, which is economically and environmentally sustainable. Furthermore, the parallel hybrid is sustainable from the energy perspective as theoretical calculations indicate that the drive system doubles the vehicle's average run time, which directly relates to the miles per gallon rating of a conventional automobile. Lastly, ethical consideration of safety and longevity resulted in upgrading the drive system with longer lasting bearings and gears in order to make the car last longer for future capstone design classes. Throughout the semester, goal setting, budget planning, and design simplification were all important things that Team Slayer learned. However, the team believes communication, both cross-team and within Team Slayer, was the single most influential and important aspect that was learned throughout the semester.

Team AMP designed an all-electric vehicle for the luxury sedan market. The goal was to produce a five-passenger, midsized entry-level flex charge sedan. On the full-scale, extrapolation of the design predicts a range of 300 miles and a rated power of 275 hp. The charge time goal for this vehicle was two hours at 220 VAC. The vehicle contains a student-fabricated onboard battery charger that has the capability to fill the batteries via either AC or DC voltages. This flex charge enables the filling of the batteries at the maximum number of locations, increasing options for the consumer when they are on the road. To further the sustainable nature of the design, home charging of the vehicle is provided through solar generation. Moreover, the students built a stainless steel space frame chassis, decreasing

Table 1. Composite scores from industrial advisory board evaluation of annual student design poster presentations

Year	Objectives	Analysis	Evaluation	Creativity	Interest	Written	Oral
2008	3.48	3.27	3.00	3.00	3.54	3.45	3.69
2010	3.46	3.32	3.20	3.01	3.52	3.62	3.65

the weight to increase the range of the vehicle. This space frame provides a stiffer ride, improving both safety and handling, which are extremely important features of a luxury sedan. A low center of gravity, 50/50 weight distribution, and coil over units were used along with a front Macpherson style and rear double wishbone suspension to improve the ride of the vehicle. Through use of wind tunnel testing, the students were able to streamline the aerodynamics of the body with an overall coefficient of drag around 0.2.

Team CranoFran incorporated all aspects of sustainability in their design of a 1/8th scale prototype vehicle intended for the midsize sedan class. The team chose to design an electric vehicle using NiMH batteries powering a Mamba Max brushless electric motor. A solar charging station, complete with a hand-made solar panel and a uni-axial tracking system, provides renewable energy for the batteries. The combination of a purely electric vehicle with solar energy results in a nearly carbon neutral vehicle. The design of the suspension, steering and tires increased vehicle efficiency through utilization of an independent Macpherson strut in the front along with a four-link style suspension in the rear. The tires chosen will be of medium hardness to optimize both handling and efficiency through consideration of rolling resistance. In order to reduce the effects of drag on the vehicle, the full-scale vehicle design will not contain side-view mirrors, instead opting for cameras and an LCD display. To make the vehicle more eco-friendly, common recyclable ABS plastic will be the base material of the body design. Finally, the chassis will bring all of the components together by using recyclable aluminum 6061-T6. This material will reduce the weight and will help to remove heat from the driveline components. Theoretical calculations along with experimentation indicate that the small-scale vehicle design achieves approximately 3900 mpg.

8. Conclusion

The goal of a new capstone design project at the University of Kansas was to follow the lead of the Engineering Education and Centers wing of the National Science Foundation in making engineering education more effective, quality conscious, flexible, simpler and less expensive. As the topic for this yearlong class, the main author chose the place of the automobile within the current and future energy infrastructure. This stems from his enthusiasm for the field along with his discussions with students indicating that the perception of automotive engineering needs enhancement with respect to energy, efficiency and the environment. To help focus the efforts in the right direction, the students chose to implement sustainable practices that involve the application of engineering techniques to solving real-world problems by holistically approaching the situation from five vectors of success: education, energy, environment, economics and ethics. In order to provide for a wide range of concepts stimulating student creativity while offering all students a manageable platform to build their unique designs, 1/8th scale Remote Control cars were chosen as the design object.

As part of the examination of the effectiveness and quality control of the Mechanical Engineering program at the University of Kansas, faculty began a yearly evaluation of senior capstone design poster presentations [57]. A rubric was created and deployed using industrial advisory board members in order to assess student performance in the areas of communication and design methodology skills. Moreover, this rubric evaluates the ability of the students to design and conduct experimental evaluation and testing. Table 1 provides the results of this evaluation in a year before the RC design project was implemented and in the first year it was implemented. While more data need to be taken and analyzed with statistical variation noted, the RC focus illustrates a positive impact on four outcomes without a significant negative influence in the other objectives. Further refinement of the program should help build on the outcomes.

While direct data assessment cannot be provided with respect to flexibility, the fact that six unique designs were theorized and constructed within a single year demonstrates a malleable project. Moreover, one team of students pushed to build a fuel cell vehicle never originally intended as an option for the class. This drove the instructor to be flexible in his original outcomes and contemplate ideas beyond those previously considered. In addition, simplicity was evident as another team was able to renovate their parallel hybrid drivetrain within a matter of months without significant difficulty. The reduced time it takes to construct and manufacture at small scale level allows students to test a concept, prove its success or failure and build a refined option. Finally, considering that each car cost on average $1200, in comparison with building an equivalent car to full scale, the program is cost efficient while achieving only a slightly reduced level of comprehension.

In the upcoming years of the design project, the main author will require more fabrication of parts as some leeway was given in the first year regarding use of production components. This will allow more computer designing, theory analysis and experimental validation, further improving the quality and effectiveness of the program. Students will be encouraged to think beyond the traditional automobile and develop revolutionary designs such as four motors per car, one per wheel. Interdisciplinary cooperation will be expanded to start using some of the designs, such as EECS regenerative braking algorithms, in ME student designed vehicles. To note, this is already occurring as one team of KU students is currently building an RC scale parallel hybrid semi-truck with Industrial Design students in another department helping design the body for aesthetics and efficiency. Finally, fostering of the program on the K-12 level will continue to occur as the students actively seek partners at elementary, middle and high schools.

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References

1. G. Kalonji, Capturing the imagination: high-priority reforms for engineering educators, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, National Academy of Engineering in the National Academies, Washington, DC, 2005.
2. National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, The National Academies Press, Washington, DC, 2005.
3. E. Seymour and N. M. Hewitt, *Talking About Leaving: Why Undergraduates Leave The Sciences*, Westview Press, Boulder, CO, 1996.
4. C. Adelman, *Women and Men of the Engineering Path: A Model for Analyses of Undergraduate Careers*, U.S. Government Printing Office, Washington, DC, 1998.
5. B. T. Wright, Knowledge management, *Presentation at Meeting of Industry–University–Government Roundtable on Enhancing Engineering Education*, Iowa State University, Ames, IA, 1999.
6. J. S. Russell, B. Stouffer and S. G. Walesh, Business case for the master's degree: The financial side of the equation, *Proceedings of the Third National Education Congress, Civil Engineering Education Issues*, American Society of Civil Engineers, Reston, VA, 2001.
7. National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*, The National Academies Press, Washington, DC, 2004.
8. C. R. Barrett, W. A. Wulf, S. E. Widnall, W. D. Compton, G. Bugliarello and W. L. Friend, *The Bridge*, National Academy of Sciences, Washington, DC, 2006.
9. R. C. Davison, *Engineering Curricula: Understanding the Design Space and Exploiting the Opportunities—Summary of a Workshop*, The National Academies Press, Washington, DC, 2010.
10. S. Doggett, http://blogs.edmunds.com/greencaradvisor/2008/07/ford-to-accelerate-lineup-shift-to-fuel-efficient-cars-after-867-billion-2q-loss.html, Accessed 27 August 2010.
11. Hybridcars.com, http://www.hybridcars.com/news/gm-announces-major-shift-away-trucks-and-suvs.html, Accessed 27 August 2010.
12. GreenBiz Staff, http://www.greenbiz.com/news/2007/06/26/chrysler-shift-its-focus-hybrid-and-fuel-efficient-vehicles, Accessed 27 August 2010.
13. Chrysler LLC, http://www.chryslerllc.com/en/about_us/our_impact/commitment_to_you/, Accessed 27 July 2009.
14. Ford Motor Co., http://media.ford.com/article_display.cfm?article_id=29505, Accessed 27 August 2010.
15. General Motors Corporation, http://graphics8.nytimes.com/packages/pdf/business/20090217GMRestructuringPlan.pdf, Accessed 27 August 2010.
16. Energy Information Administration, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html, Accessed 27 August 2010.
17. J. Lou, http://www.eia.doe.gov/emeu/international/gas1.html, Accessed 27 August 2010.
18. Energy Information Administration, http://www.eia.doe.gov/emeu/steo/pub/contents.html, Accessed 27 August 2010.
19. KPMG International Cooperative, http://www.kpmg.se/download/106534/143048/Global_Automotive_Survey_2008.pdf, Accessed 27 August 2010.
20. General Motors Corporation, http://www.gm.com/corporate/responsibility/environment/news/2008/challenge_050808.jsp, Accessed 27 August 2010.
21. R. M. Heavenrich, *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2006*, U.S. Environmental Protection Agency, EPA Report 420-R-06-011, 2006.
22. C. Isidore, http://money.cnn.com/2008/12/04/news/companies/senate_hearing/index.htm, Accessed 27 August 2010.
23. National Highway Traffic Safety Administration, http://www.nhtsa.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/, Accessed 27 August 2010.
24. J. M. Broder, http://www.nytimes.com/2010/04/02/science/earth/02emit.html?_r=2&src=me, Accessed 27 August 2010.
25. J. D. Bransford, A. L. Brown, J. R. Anderson, R. Gelman, R. Glaser, W. T. Greenough, G. Ladson-Billings, B. M. Means, J. P. Mestre, L. Nathan, R. D. Pea, P.L. Peterson, B. Rogoff, T. A. Romberg and S. S. Wineburg, *How People Learn: Brain, Mind, Experience and School*, National Academy Press, Washington, DC, 2004.
26. G. H. Brundtland, Global change and our common future, *Environment*, **31**(5), 1989, p. 16.
27. F. Barnaby, Our common future–The Brundtland-Commission Report, *Ambio*, **16**(4), 1987, pp. 217–218.

28. United States Congress, http://ceq.hss.doe.gov/nepa/regs/nepa/nepaeqia.htm, Accessed 27 August 2010.
29. M. H. Bremer, E. Gonzalez, and E. Mercado, Teaching creativity and innovation using sustainability as driving force, *International Journal of Engineering Education*, **26**(2), 2010, pp. 430–437.
30. S. R. Turns, L. L. Pauley and S. E. Zappe, Active and collaborative learning in a first course in fluid mechanics: Implementation and transfer, *International Journal of Engineering Education*, **25**(5), 2009, pp. 979–997.
31. J. Wren, J. Renner, R. Gardhagen and K. Johansson, Learning more with demonstration based education, *International Journal of Engineering Education*, **25**(2), 2009, pp. 374–380.
32. D. N. Huntzinger, M. J. Hutchins, J. S. Gierke and J. W. Sutherland, Enabling sustainable thinking in undergraduate engineering education, *International Journal of Engineering Education*, **23**(2), 2007, pp. 218–230.
33. C. Depcik and D. Assanis, One-dimensional automotive catalyst modeling, *Progress in Energy and Combustion Science*, **31**(4), 2005, pp. 308–369.
34. P. Kurowski, Good Solid Modeling, Bad FEA, *Machine Design*, **68**(21), 1996, pp. 67–72.
35. P. Kurowski, Avoiding Pitfalls in FEA, *Machine Design*, **66**(21), 1994, p. 78.
36. P. Kurowski, When Good Engineers Deliver Bad FEA, *Machine Design*, **67**(20), 1995, p. 61.
37. U. S. Deparment of Energy, http://www.cfo.doe.gov/strategicplan/energysecurity.htm, Accessed 27 August 2010.
38. V. Lightner, KU Energy Council Conference Biomass Program Overview, *KU Energy Council: 1st Annual Conference*, 5 November 2008, Lawrence, KS.
39. U.S. Department of Energy, http://www1.eere.energy.gov/solar/solar_america/index.html, Accessed 27 August 2010.
40. Council on Competitiveness, http://www.compete.org/publications/detail/202/innovate-america/, Accessed 27 August 2010.
41. University of Kansas Biodiesel Initiative, http://biodiesel.ku.edu/index.php, Accessed 27 August 2010.
42. Sandia National Laboratories, increasing diesel fuel volatility can significantly improve efficiency and emissions under early direct-injection, low-temperature combustion conditions, *Combustion Research Facility Newsletter*, Sandia National Laboratories, Livermore, CA, 2009.
43. J. Voelcker, http://spectrum.ieee.org/green-tech/advanced-cars/can-plugin-hybrid-electric-vehicles-keep-the-electric-grid-stable, Accessed 27 August 2010.
44. S. Silke Carty, http://www.usatoday.com/money/autos/2009-03-05-used-hybrids_N.htm, Accessed 27 August 2010.
45. A. Raskin and S. Shah, http://www.calcars.org/alliance-bernstein-hybrids-june06.pdf, Accessed 27 August 2010.
46. Environmental Protection Agency, *Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use*, EPA Report 420-F-07-035, 2007.
47. Society of Automotive Engineers International, http://students.sae.org/competitions/formulaseries/, Accessed 27 August 2010.
48. Shell.com, http://www.shell.us/home/content/usa/environment_society/eco_marathon/, Accessed 27 August 2010.
49. T. L. Friedman, *Hot, Flat, and Crowded : Why we Need a Green Revolution, and How it can Renew America*, Farrar, Straus and Giroux, New York, 2008.
50. The White House, http://www.whitehouse.gov/issues/energy-and-environment, Accessed 27 August 2010.
51. C. Squatriglia, http://blog.wired.com/cars/2009/02/hot-wheels-mi.html, Accessed 27 August 2010.
52. J. J. Stone, http://gas2.org/2009/07/13/students-build-hydrogen-vehicle-that-gets-1336-mpg/, Accessed 27 August 2010.
53. S. B. Sitkin, Learning through failure: The strategy of small losses, *Organizational Learning*, Sage, Thousand Oaks, CA, 1996.
54. L. Stiffler, http://seattlepi.nwsource.com/local/361634_biodiesel03.html, Accessed 27 August 2010.
55. J. Hirsch, http://articles.latimes.com/2010/jul/27/business/la-fi-autos-volt-20100727, Accessed 27 August 2010.
56. Environmental Protection Agency, http://www.epa.gov/oms/consumer/fuels/altfuels/420f00034.htm, Accessed 26 November 2010.
57. S. Wilson, P. TenPas, R. Dougherty, C. Depcik and K. Fischer, Evaluating student learning across the mechanical engineering curriculum, *2010 ASEE Midwest Section Conference*, Lawrence, KS, 22–24 September 2010.

Appendix A

Table A1. University of Kansas engineering classes for Mechanical Engineering degree and how RC cars can provide a common thread

Number	Name	Description	RC synergies
CE 201	Statics	The principles of statics, with particular attention to engineering applications	Hand calculation of center of gravity[1]
ME 208	Introduction to Digital Computer Methods in ME	Digital computing methods for solving mechanical engineering problems utilizing current programming languages and commercial software	Programming techniques for modeling[9]
ME 228	Computer Graphics	Introduction to graphics programs, introduction to computer aided design, familiarization with computer graphics hardware and software	CAD model of simple pan chassis, creation of properly dimensioned engineering drawings[1, 5, 7]
ME 306	Science of Materials	Emphasis is placed on structure and the relation of structure to the behavior and properties of engineering materials	Chassis material properties[1]
ME 307	Engineering Materials Lab	Laboratory to supplement lecture on engineering materials properties and selection, manufacturing processes, and design for manufacturing	Use of machine shop in fabrication[1, 5]
CE 310	Mechanics of Materials	Principles of stress and deformation in structures and machines	Fracture and fatigue points of different construction materials, hand calculation of chassis deflection[1, 5]
ME 312	Basic Engineering Thermodynamics	An introduction to the concepts of heat, work, the first and second laws of thermodynamics and equations of state	Biodiesel fuel combustion balance [2]
EECS 316	Circuits, Electronics and Instrumentation	Introduction to DC and AC electrical circuit analysis, operational amplifiers, semiconductors, digital circuits and systems, and electronic instrumentation and measurements with a focus on applications	Theory behind batteries and electric motor control[3, 4, 6]

Number	Name	Description	RC synergies
EECS 318	Circuits and Electronics Lab	Experiments include DC circuits, analog electronics, and digital electronics	Measurement of voltage, amperage and power[3, 4, 6]
ME 412	Thermal Systems	Application of the principles of thermodynamics to the analysis and design of thermal systems	Two-stroke thermodynamic cycle[2]
ME 420	Mechanisms	Kinematic design and analysis of mechanisms composed of linkages, cams, and gears	Steering linkage, suspension travel, transmission[2, 3, 5]
ME 455	ME Measurement and Experimentation	Lectures and laboratories on the basics of measurement, instrumentation, data acquisition, analysis, design and execution of experiments, and written and oral reports	Experimental error analysis, experimentation on spring-damper type system[1, 2, 3, 5]
ME 501	ME Design Process	The design process of a mechanical or thermal system. Establishment of specifications and consideration of realistic constraints such as safety, codes, economic factors, reliability, oral and written communications, and other factors as they impact the design process	Engineering decision making, working as a team with common focus[8]
ME 508	Numerical Analysis	Introduction to numerical methods for solution of mechanical engineering problems by use of digital computers	Models of drivetrain efficiency[2, 3, 4, 6]
ME 510	Fluid Mechanics	An introduction to the mechanics of fluid flow. The principles of conservation of mass, momentum, and energy are developed in differential and integral form	Drag force, coefficient of drag, Reynolds number scaling theory[7]
ME 520	Dynamics of Machinery	Kinetic design and analysis of mechanisms. Mechanical vibration	Drivetrain vibration, determination of mass properties (e.g. COG, MOI), suspension angle optimization[1, 2, 3, 4, 5, 6]
ME 528	Mechanical Design I	Design of mechanical components and systems	Design of suspension and chassis[1, 5]
ME 612	Heat Transfer	An applied study of conductive, convective, and radiative heat transfer mechanisms in solid and fluid systems	Fins for cooling, dissipation of heat from battery pack and speed controller[2, 4, 6]
ME 628	Mechanical Design II	Design of mechanical components and systems	Integration of suspension with chassis[1, 5]
ME 636*	Internal Combustion Engines	Study and analysis of internal combustion engine physical phenomena dynamic function, components, and system design	Two-stroke timing diagram, biofuels and thermodynamic cycle[2]
ME 661	Finite Element Method for Stress Analysis	An introduction to the underlying theory of the finite element (FE) method and its application to solid mechanics	Fundamentals behind finite element analysis software[1]
ME 682	Control Systems	An introduction to the modeling, analysis, and design of linear control systems	Program control algorithms behind electronic speed controller, cruise control, steering servo, etc.[6]

* Technical elective. Superscript and their associated RC car project design component: [1] Floorpan type chassis; [2] 'Nitro' two-stroke internal combustion engine; [3] Brushless electric motor; [4] Lithium battery pack; [5] Double wishbone suspension; [6] Electronic speed controller; [7] Truck body design; [8] Proposal writing, presentations and reports; [9] Theoretical models.

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