AC 2010-482: ENHANCING OUTREACH THROUGH A SUMMER HANDS-ON ENGINEERING WORKSHOP

Robert Rabb, United States Military Academy

John Rogers, United States Military Academy

Enhancing Outreach through a Summer Hands-On Engineering Workshop

Abstract

The United States Military Academy (USMA) at West Point conducts a week long outreach program to approximately 800 high school juniors every summer. Students enjoy the academic offerings and see USMA's programs in action through current students who help coordinate the seminar activities. The overall goal is to give potential students an inside look at the institution's student life in all areas to include academics, athletics, and leadership. Seminar attendees select their courses from a variety of offerings from all academic departments at the institution. This paper describes the Department of Civil and Mechanical Engineering's program. The goal of this particular workshop is to give the attending students an overview of different disciplines of engineering and enlighten them that engineering is fun and practical. Classes are small, and our instructors are very engaging and helpful. Students engage in hands-on experiences, including many in the institution's modern computer and laboratory facilities. They attend lessons in engineering fundamentals and are presented with potential, real world problems. The students apply the design process to solve these problems in small teams. In this two-part workshop they participate in this process, constructing their design. For mechanical engineering, students will be presented with a real-world challenge and have the opportunity to design, build and test their solution using Lego motors and pieces. The challenge simulates delivering much-needed supplies to people stranded on a hillside. The students will learn engineering fundamentals about torque, power and gear trains and be able to directly apply those concepts to the design. This workshop also combines an overview of what mechanical engineering is and what type of problems mechanical engineers can be expected to solve. For civil engineering part of the workshop, the students discuss the civil engineers' role in planning, designing, building, operating and maintaining the nation's infrastructure. Students will use computer modeling and simulation tools to design, build and test a truss bridge. Students will also design and build a bridge out of K-nex components, and load the bridge to failure in a competition. Surveyed participants overwhelmingly praise the hands-on learning.

Introduction

According to the 2006 Program for International Student Assessment (PISA), 15-year-old U.S. students ranked at the bottom third for both mathematics and science compared to all other countries that participated.[1] The U.S. has seemingly fallen behind other developed countries, in educating the students to succeed in the math and science curriculum. Many fields of engineering seem ambiguous or obscure to many students in K-12 institutions. In addition, the more familiar fields of math and science are looked upon as difficult and unattainable. Their peers in other countries consistently outperform students in the United States. Some reasons that many students have shifted away from engineering is an incomplete picture or understanding of the engineering profession and a loss of interest in science and math.[2] Unless a student has a relative who is an engineer, it is doubtful that he or she will see a role model who can expose them to the interesting opportunities in engineering.[3]

USMA hosts the Summer Leaders Seminar (SLS) for high school juniors entering into their senior year. The weeklong program of academic classes, leadership training, physical fitness training and intramural athletics gives students the opportunity to experience campus life and to see first-hand what West Point has to offer. Each year 800 highly talented high school juniors are invited to attend the SLS, which is led and supervised by the current student body who act as cadre. The program has been so successful that it will expand to 1000 students next summer. The seminar offers a variety of courses from which to choose. Classes are small, typically 18. The instructors who lead the academic portion of the seminar are typically regular faculty members and are very helpful because they are practiced at small, hands-on classes. West Point has assembled several hands-on activities and demonstrations for a wide variety of students to include use and exposure to some of the modern computer and laboratory facilities. Students indicate before attending which three academic departments they wish to visit. They spend a day in one of these departments when not engaged in the seminar's athletic or leadership events. This paper will focus on the Department of Civil and Mechanical Engineering's experience with the students choosing the department as part of their Summer Leaders Seminar. Approximately 200 of the yearly SLS attendees participate in the Department of Civil and Mechanical Engineering's program. This seminar does require resources and coordinators and instructors are assessing the program's ability to change student perceptions about engineering. Additionally, specific information on the mechanical engineering Lego exercise will be presented.

Recruiting highly talented future students is a secondary goal of the seminar. The primary focus is to educate and excite students about engineering, developing a foundation for appreciation and understanding of these important disciplines. Additional goals of the department include: expanding the interest and enthusiasm for the field of engineering as a possible academic path or career, and modeling practicing engineers. Only faculty who have served in the department for at least one year can instruct during SLS, and to gain maximum exposure to engineers, instructors often team teach and assist one another.

The students arrive in groups of 36 or fewer with half going to the civil engineering instructor in the morning, and the other half going to the mechanical engineering instructor. In the afternoon, groups switch disciplines. The students have a total five hours with each department. The program is designed to include a brief introduction of the department and specific areas of interest to highlight some of our current or newer projects. The student groups then receive a short briefing about the specific discipline and a look at a few of the sub-disciplines the department offers. The instructors present an engineering design problem to the students and teach enough fundamentals for them to apply and arrive at a solution. The students build their solution in a hands-on exercise in an effort to involve as many of them as possible using small groups of two to three. Instructors may present their own solution or demonstration. However, the demonstrations are not designed to be elaborate or sophisticated, but rather to be interesting and easily explained so the students are left feeling that they understand the math and science involved. Impressing them with sophisticated design solutions is not the intention. Instructors circulate during the build phase, constantly engaging the students to prevent "lulls" in the classroom. For the civil engineering component of the workshop, the students conduct a truss analysis and design a model bridge over a given span in order to support a specified load (Figure 1). K'nex and Legos are common building components and toys to practically of the students, so any familiarization with either kit is not necessary which allows more time to learn engineering concepts and hands on exercises. This paper will focus on the details of the mechanical engineering exercise, but the results are similar for the civil engineering workshop.

Figure 1: K'Nex Bridge under Load Testing

For the mechanical engineering exercise, the students conduct a gear train analysis (power and torque) and build a winch with a Lego gear set to lift a specified load in the shortest amount of time (Figure 2). The exercise scope strikes a balance between easy and quick on one hand and overly challenging on the other hand. The engineering requirements and constraints are demanding enough to reinforce that the disciplined design method is superior to the build and test approach without analysis. Two and a half hours is allotted to the introduction to the engineering discipline, instruction, and hands-on exercise. This is a suitable period; it allows for comfortably paced instruction followed by practical design and construction. Most student products are simple enough to build such that they have enough time to iterate for a better solution. Students are encouraged to improve their design after testing and develop better solutions when time allows. Instructors do have sample winches and demonstrations for the students to see and compare their designs (Figure 3).

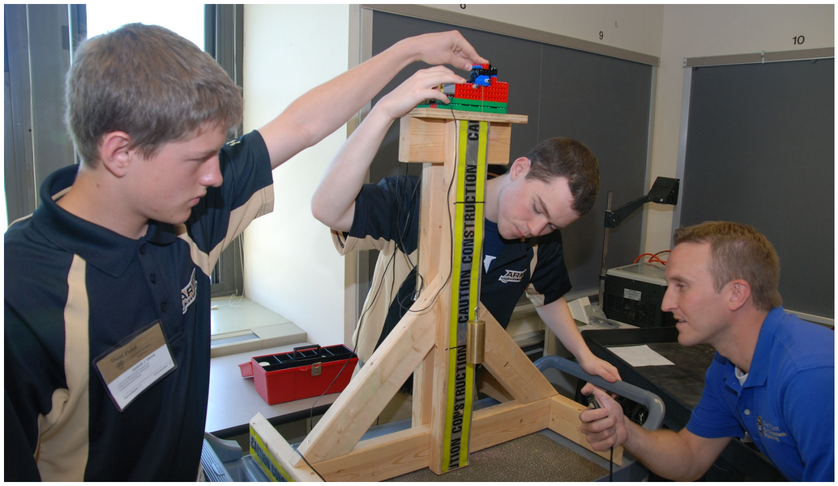


Figure 2: Testing a Lego Gear Set

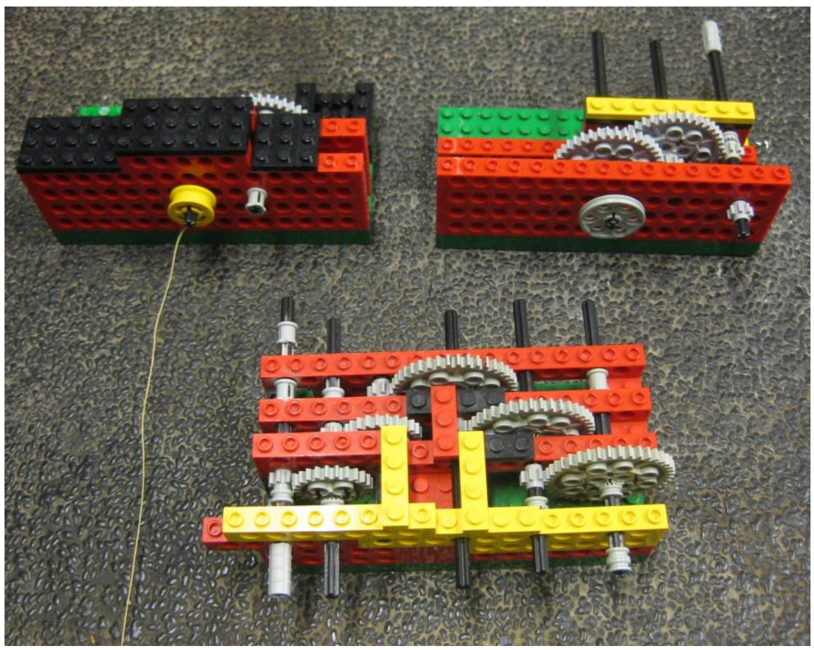


Figure 3: Sample Instructor Winches and Demonstration

Each morning and afternoon session generates a class contest and winning group for the class. The overall winners for the week are recognized during a closing ceremony for the entire SLS. These small contests keep the students engaged and excited, and many outreach programs have seen the benefit of sponsoring engineering contests both large and small.[4] At the conclusion of the class competition, students reorganize all their components. The instructor reiterates the engineering design process, and USMA students are free to answer questions concerning engineering or any institution specific questions. If there is additional time the instructor leads a short discussion about how other engineering problems may be solved, trying to relate back to some of the instructional material. For students to learn about engineering, the students must be engaged and do the engineering themselves. Reading about the theory and applications is inadequate to get a real engineering experience. The students must be immersed in observation, questions, prediction, testing, and design.[5]

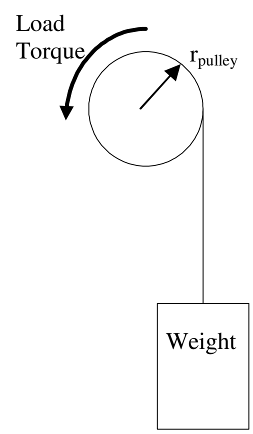
Sample Exercise (Mechanical Engineering)

This section describes the hands-on exercise of the mechanical engineering portion of the workshop.

Background material on gears is covered by instructors and is reiterated in a take-home workbook (Appendix A). All winch designs constructed by the students are tested on a standard fixture with a fixed power supply and motor, so there is no variance due to electrical components. Lego motor torque, speed, and power characteristics (Appendix B) are also provided to the students in the workbook.

The workbook provides detailed instructions and space for calculations of the gear train analysis. The following is a brief summary of the steps.

Step 1: Determine payload weight (Payload = ___ g = ___ lbf)
Step 2: Calculate the torque (T_{load}) that the shaft must provide to lift the payload.
Step 3: Find the motor operating torque T_{motor} from the motor power vs. torque curve
Step 4: Estimate the actual torque ratio (m_a) you will need to lift the payload.
Steps 5 and 6: Calculate the ideal torque ratio and the gear ratio
Step 7: Select the number of Gear Sets you want to use in your gear train.
Step 8: Build your gear train!
Step 9: Test and troubleshoot your winch.
Step 10: Record the time to lift the payload and the distance the payload moved. Calculate the payload velocity.
Step 11: Compare your actual power to the design (power curve peak)



These steps are interspersed with tables, equations, and unit conversions in the workbook.

The faculty maintains ten Lego kits, enough for a class size of 18 students (Figure 4). The kits contain a variety of Lego pieces, several pulleys, plastic dial calipers, a calculator, and an 800-gram mass. The motor is not strong enough to lift the load directly, so a gear train is required. The calipers are used by the students to measure the diameter of each pulley. The design has three primary parameters: the pulley diameter, the number of gear sets, and the overall gear ratio. The design is underconstrained with this many parameters, in other words there are many combinations that will accomplish the task satisfactorily. The students must start their design by selecting a pulley, and they normally do so without understanding the design implications. The pulley selected by the students for their design has a bearing on the gear train design; a larger pulley requires more torque at the output shaft than a smaller pulley does. This fact is not readily apparent to the students until they complete the analysis and possibly must return to compute another design iteration with a different pulley. The engineering objective of the design is to maximize the power from the motor by operating the motor in the "power band." The power band is the area close to the peak of the Power Curve. Frictional power loss is accounted for by including efficiency in the analysis. The participants see how math is applied in the solution of a problem.

This hands-on exercise yields many interesting results. Some student groups submit simple products that produce a winner the first time with a score that stays at the top of the scoreboard all day. Some of the groups will work diligently and try to better their times, iterating five or more times on the test stand. A small number of groups will attempt elaborate designs that fail to even lift the specified load. The class goal is to achieve a working design that produces a time (score) upon which they can improve.

Figure 4: Standardized Lego Kit

The civil engineering portion of the workshop uses K'nex components for building material and instructors host a similar challenge exposing the participants to truss analysis. A high strength to weight ratio is desired and time is factored into the overall product.

Discussion

Of the 800 students who attend SLS every summer, approximately half are accepted and attend the institution. There is no statistical data to track the three academic departments visited by the high school juniors and correlate to the major they chose a year after attending the school. In a typical class, the department averages about 55 civil engineering majors and 75 mechanical engineering majors, annually. A recent survey of our civil and mechanical engineering majors showed that over 54% stated that their previous interest and experience in engineering was the most important influence that led to their decision (Figure 5). One note is that two to three years had elapsed from the time they attended the workshop until they answered the survey. Of these, approximately half of the mechanical engineers indicated they attended SLS. Many of the majors have specifically told us that these hands-on exercises were their first academic exposure to engineering. This experience has helped the department to achieve the goal to educate and excite students about engineering so they can appreciate and understand these important disciplines. Surveyed workshop participants consistently rate the Civil and Mechanical Design Workshop highly, and cite the hands-on approach as their reason. We believe that indirectly, this experience has helped us recruit highly talented future students.

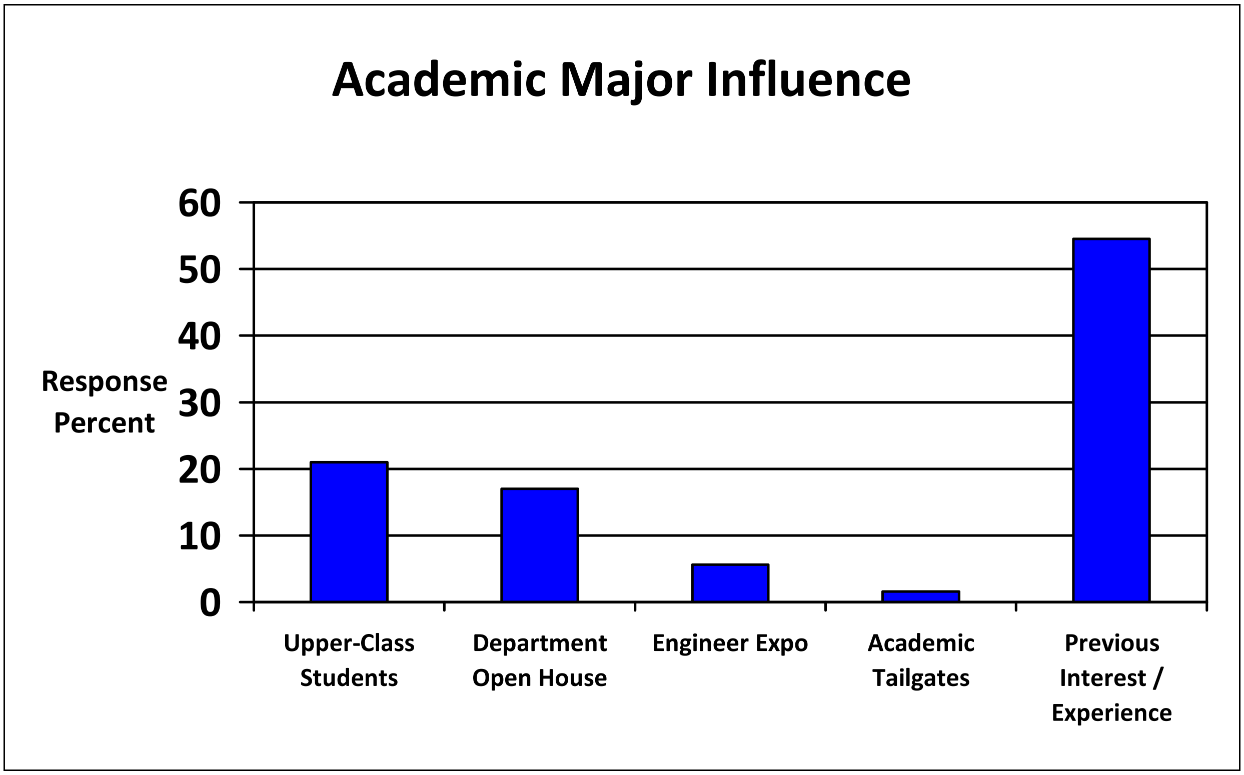


Figure 5: Most Important Influence in Selecting Academic Major

One of the coordinator's goals was to assess the effectiveness of the department specific seminar. A look at the feedback data from recent students attending SLS shows some interesting and encouraging results. The following scale (Table 1) was used for the students' survey:

Table 1: Assessment Scale

1	2	3	4	5
strongly disagree	disagree	neutral	agree	strongly agree

For the most part, the students agree that the department's specific program is a positive experience for them. Particular ratings that are addressed in the discussion are indicated on the graph (Figure 6). The potential students indicated the Lego and K'nex exercises improved their understanding of the respective disciplines. This is an improvement over their understanding before attending. Similarly, before attending, students had a mild interest in civil or mechanical engineering, indicated with a 3.65. However, after the experience in the department, their inclination to study one of the disciplines registered 3.81. This may not be a remarkable difference, but it is a positive improvement that infers the SLS Workshop has some impact. The feedback collected was one indicator of the positive impact from the seminar.

Additionally, these simple hands-on exercises appear to be effective to increase interest and enthusiasm for engineering as a possible academic path or career. Student comments and discussion on the student surveys reinforce their overall ratings. Free text survey responses are consistently positive as noted below:

> "I don't know too much about engineering, and I'm not too great at math… so I thought I would hate it, but I really enjoyed it."
>
> "I was very entertained with my experience. It was extremely fun. I want to really be a part of this and would like to do this as my major, hopefully at USMA. It was more than interesting."

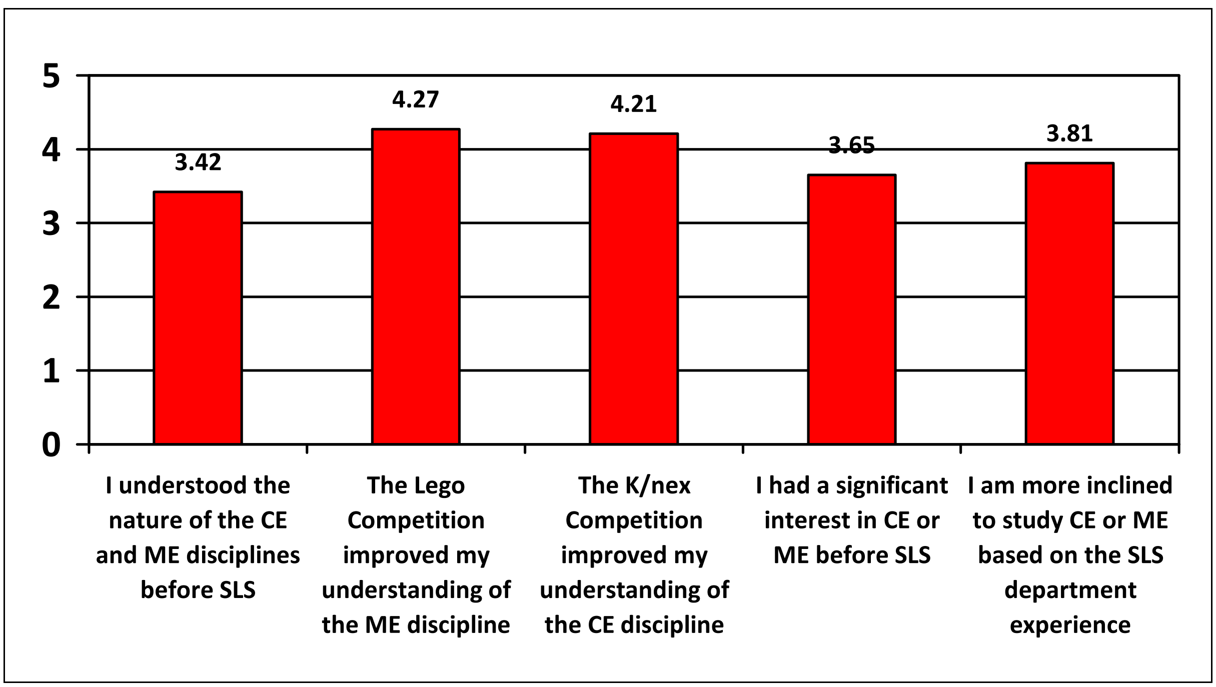


Figure 6: Student Objective Feedback

Lessons Learned

The Department of Civil and Mechanical Engineering Summer Leadership Seminar is an evolving event. Each year we learn and try new ideas. It is important to have a detailed lesson conference to demonstrate the flow of the lesson and the demonstrations. Additionally, some groups of students try to find the perfect solution and spend a large part of their time analyzing and building robust gear sets. We have learned that the best solutions are produced by the teams that build a working solution and can iterate subsequent solutions. We have learned to remove some gears and components (i.e. worm gear) that contribute to novel solutions but constrain the design team. Although the students are usually above average, many need sample calculations done in the workbooks and less theory in order to produce a working solution.

Conclusion

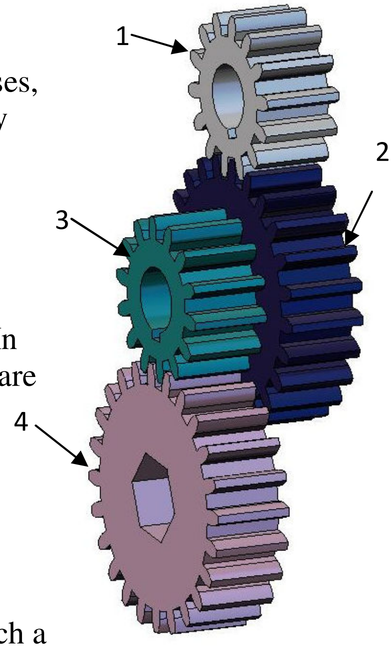
In this paper we have described the success and experience of a department's outreach to high school juniors as part of a week-long summer workshop sponsored by the institution. Students and instructors enjoy the SLS experience due to the hands-on involvement of an engineering problem. The program's dual goals address outreach and recruiting. Satisfaction of the goals is difficult to track statistically, but facts tend to suggest that these goals are being met. Approximately 50% of the current mechanical engineering majors attended an SLS session.

Bibliography

1. Institute of Education Sciences (IES), Highlights from PISA 2006: Performance of U.S. 15-Year-Old Students in Science and Mathematics Literacy in an International Context, U.S. Department of Education NCES 2008-016, December 2007.
2. Fadali, M. S., Robinson, M., and McNichols, K., ''Teaching Engineering to K–12 Students Using Role Playing Games,'' *Proceedings of the 2000 ASEE Annual Conference*, St. Louis, MO.
3. Abbitt, J. D., III, and Carroll, B. F., ''Applied Aerodynamics Experience for Secondary Science Teachers and Students,'' *Journal of Engineering Education,* 1993 v.82 (3), 185–188.
4. Jeffers, A., Safferman, A., and Safferman, S., "Understanding K-12 Engineering Outreach Programs," Journal of Professional Issues in Engineering Education and Practice, 2004, April, 95-108.
5. Biernacki, J. J., Walhof, L., and Shao, Y., ''Infrastructure materials: An inquiry-based design sequence.'' *Proceedings of the 1997 ASEE Annual Conference,* Washington, D.C.
6. LEGO Gearing (http://www.owlnet.rice.edu/~elec201/Book/legos.html).

Appendix A

Gear Basics



Gears transmit torque (T) and angular velocity (ω). If torque increases, angular velocity must decrease. If torque decreases, angular velocity must increase. Terms associated with gears:

NUMBER OF GEAR TEETH (N): the number of teeth on a gear.

GEAR SET: a set of two gears whose teeth are in contact (meshed). One gear (driving gear) causes the other gear (driven gear) to turn. In the figure to the right, gears 1 and 3 are driving gears, gears 2 and 4 are driven gears.

Gears 2 and 3 are fixed together so they rotate at the same speed.

GEAR TRAIN: collection of one or more gear sets.

ANGULAR VELOCITY (ω, Greek letter omega): The speed at which a gear rotates in radians per second.

TORQUE (T): an effort that tends to rotate or turn things

$$T = F * r_{pulley}$$

where
F = the weight of the payload [lbf]
r_{pulley} = radius of the pulley attached to the shaft [in]

POWER (P): rate at which work is done. For a rotating shaft,

$$P = T * \omega \quad \text{or} \quad P = T * RPM \frac{[rev]}{[\min]} * \frac{2\pi[rad / rev]}{60[\sec/\min]}$$

The 2π / 60 is a unit conversion from RPM to radians per second.

ANGULAR VELOCITY RATIO (m_v): relative angular velocity of two gears in contact, expressed as a function of gear teeth.

$$m_v = \frac{\omega_{OUT}}{\omega_{IN}} = \frac{\Pi(N_{DRIVING})}{\Pi(N_{DRIVEN})}$$ (Π means "product of," just like Σ means "sum of")

TORQUE RATIO (m_a): relative torque of two gears in contact. The actual torque ratio is the ratio of the torque actually achieved at the output of the gear train to the torque provided by the motor to the input of the gear train.

$$m_{a(ACTUAL)} = \frac{T_{OUT}}{T_{IN}} \quad \text{or} \quad m_{a(ACTUAL)} = \frac{T_{LOAD}}{T_{MOTOR}}$$

The actual torque transmitted through two meshing gears is less than the ideal torque due to losses from friction and vibration (see efficiency below). This loss is expressed by the Greek letter eta "η," for efficiency.

$$m_{a(IDEAL)} = \frac{m_{a(ACTUAL)}}{\eta^{(\#GEAR SETS)}}$$

GEAR RATIO (m_G): relationship between the number of teeth on gears that are meshed. The gear ratio of the gear set should be as close to the ideal torque ratio as possible.

$$m_G = \frac{\Pi(N_{DRIVEN})}{\Pi(N_{DRIVING})} = \frac{(N_{DRIVEN})}{(N_{DRIVING})_{GEAR\ SET\ 1}} * \frac{(N_{DRIVEN})}{(N_{DRIVING})_{GEAR\ SET\ 2}} * \frac{(N_{DRIVEN})}{(N_{DRIVING})_{GEAR\ SET\ 3}} \cdots$$

EFFICIENCY: decimal value expressing how well a gear set is able to preserve torque as it is transferred between gears (higher number is more efficient). Gears do not perform perfectly due to losses from friction and vibration. The efficiency describes how closely to the ideal that the gear set performs. Lego gears have an efficiency of about 0.60 (60%).

REMEMBER, EFFICIENCY (η) EFFECTS TORQUE AND POWER, BUT *NOT* ANGULAR VELOCITY!

Appendix B

Lego Motor Characteristics