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USING STUDENT DESIGN PROJECTS FOR SECONDARY SCHOOL OUTREACH

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Abstract

The authors have developed a senior design capstone project that permits students to design for and participate in outreach activities. Senior undergraduate students work in teams to design demonstration apparti intended to promote enthusiasm for the profession of engineering in high school students. This paper recounts our pilot project in this regard. Of the ten designs developed by the senior class, the two best designs were constructed by students. One was actually deployed in a high school outreach activity; it was so successful that it has been adopted as a "standard" demonstration by a provincial body responsible for such work. While not all undergraduate students appreciated the design challenge, this initiative was a success and we hope to implement it again in future years.

Keywords: project-based learning, outreach program, undergraduate design

1 Introduction

The authors team-teach a one-semester (four months) senior undergraduate course in mechanical systems design at Ryerson University. One of the course objectives is to encourage students to "think outside the box" and to develop designs that are as innovative as possible. To do this, we define design projects that are intentionally ill defined and atypical of those given to students in other courses, yet just complex enough that teams of undergraduate seniors can develop relatively complete solutions within one semester.

At the same time, Ryerson's Faculty of Engineering and Applied Science is constantly seeking new and interesting ways to reach out to students in high schools and who are considering their choices for a university education. Ryerson, which became a university only a decade ago (it was a polytechnic institute previously, which awarded only diplomas but no degrees), finds itself in stiff competition with other, more established universities, and we are very interested to find distinctive ways to present Ryerson to prospective students in high school.

The authors took advantage of a funding opportunity to combine these two different yet sympathetic goals into a single initiative: have the senior design students develop and build demonstration apparti that can be used for outreach purposes in high schools.

This paper will recount the authors' effort with this initiative and suggest that the kind of synergy we have found between senior undergraduate design projects on the one hand, and the need for innovative outreach techniques can be beneficial to all stakeholders. While we only have anecdotal evidence, we believe this project was successful in many ways.

2 Background

In Canada, each province has a regulatory body for engineering; in Ontario, it is Professional Engineers Ontario (PEO). The PEO is in charge of licensing and monitoring the professional practice of engineers in Ontario. It also undertakes certain activities to promote the profession to young people. Under this mandate, members of PEO from Ryerson University visit secondary schools in the Toronto area during National Engineering Week each March, to promote interest in entering the profession. Ryerson vies for students with many other Ontario universities. There is therefore a certain friendly competition between universities to put on the best possible promotional visits.

The high school students who attend these information sessions are quite sophisticated. They are not convinced by simple pictures of happy, handsome university students attesting to the quality of the studies and student life at a given university, nor are they convinced by lists of past graduates from a university who went on to important achievements or great wealth. (Indeed, one might argue that one would prefer *not* to enrol students who would place a priority on wealth or status.) Students can be swayed, however, by demonstrations of technical expertise and other matters of direct concern to the average practising engineer. Such demonstrations engage the students – particularly if the students themselves are active participants in the demonstration – and make the students understand the direct interest that a university has in them as individuals. Thus, these high school visits can benefit by having demonstration apparati to deliver high-quality presentations. However, no such apparti currently exist at Ryerson and there is no funding to develop them.

In the School of Mechanical Engineering at Ryerson University, the course MEC723, Mechanical System Design, is a senior year design course in which students work in teams to solve open-ended problems. Enrolment in the course is typically between 50 and 60 students (slightly over 50% of the senior year in mechanical engineering). A key feature of the course is a semester-long, team-based design project, which promotes collaboration and gives students a chance to work on a significantly large project. One faculty goal has been to find "real world" problems that are not exclusively industrial in nature, to broaden the students' perspective on the roles that engineers can play in society, and to let students exercise their "creative muscles" as they seek innovative solutions. This is something not typically done in our current mechanical engineering curriculum. We note that we take the term "innovation" in a relative sense here. That is, if the students are able to develop a design solution that is novel *in their experience*, we consider that an innovative solution whether or not the solution actually already exists.

The authors developed an initiative that blends these two needs. In the 2001 Fall semester, the student teams in MEC723 designed demonstration apparti to showcase principles of mechanical engineering for secondary school students. After the end of the semester, the teams who created the two best designs were invited to build their devices and travel to a secondary school to conduct a demonstration during National Engineering Week in March 2002.

MEC723 is taught once weekly, in a single four-hour block combining both "lecture" and "laboratory" periods. We have found that this arrangement, while sometimes onerous on both instructors and students, gives us the flexibility to use the four-hour periods in whatever format is best suited to the particular material being presented in any given period.

The course focuses on the upstream stages of design, leading up to the development of CAD drawings. These stages include design problem analysis, customer needs and requirements analysis, ideation, concept design and evaluation, systems design, and product architecture development. The students are also expected to carry out detailed design of their solutions, but since this stage is amply covered in prerequisite courses, it is not expressly treated in MEC723.

Rather than concentrating on one method or tool, such as Axiomatic Design [1], our approach is to present to students principles drawn from different methods, all connected together through a set of tools partly drawn from the literature and partly developed by the instructors. Some of these principles include the two axioms of Axiomatic Design; reasoning by analogy [2], function inversion [3], and brainstorming [4] for concept design; the use of weighted decision matrices [5] and pairwise comparisons [6] for concept evaluation; and concept maps [7] and product architecture schematics [8] for systems design. Additionally, some materials on project management and collaboration are also presented to help support the student design teams. These methods and tools are connected together in a "Design Roadmap" that leads the students through the overall process. The roadmap can be viewed online at http://deed.ryerson.ca/mec723 (and select the *lecture notes* link).

A MBTI-style *personality type indicator* (PTI) is used to assess students at the beginning of the course. Rules [9, 10] are used to compose the student teams (five students per team on average). The PTI is carried out online via the World Wide Web using software written by Salustri (interested readers may take the PTI themselves at http://deed.ryerson.ca/pti). In the authors' experience, teams formed using the PTI tend to function better than when the indicator is not used. This conclusion is based on anecdotal evidence over six years experience teaching junior, senior, and graduate design classes at two Canadian Universities and is itself the subject of future study by the authors. However, there is some evidence from the literature that supports our experiences [9].

Bi-weekly assignments let students practice various design methods and tools individually and in their teams, in preparation for their application to the design project. In-class studio exercises give students the opportunity to practice the methods and tools so that the students can apply them more quickly and effectively to their term projects.

Deliverables of the team project include a written report with full CAD drawings and an oral presentation made to the class and an industry representative in the role of a "external" examiner. The industry representative provides the industry/business perspective on the merits of each team's design. While the assessment made by the industry representative is usually compatible with that of the instructors, the industry perspective tends to make the students more aware of the far-reaching implications of their designs to the economic and corporate health of the (admittedly hypothetical) client companies of the design teams.

3 The outreach apparatus project

The preceding section described the course in general terms. Below, the authors will explain the specifics of the "outreach apparatus" design problem in the Fall 2001 semester offering of MEC723.

The students were given a short background presentation on the nature of outreach activities. Many students recalled participating in such activities when they were in high school, but most had never considered the matter from the point of view of those *doing* the outreach. Then, the students were assigned the problem: design a portable demonstration apparatus, suitable for use during typical outreach activities in high schools, so as to raise the awareness and interest of the audience (high school students) to consider a University education in mechanical engineering at Ryerson.

The initial stages of the design process were particularly difficult for the students to execute, because they had only ever designed to problems that were of a "conventional" mechanical engineering character. We advised them to first consider the characteristics of a demonstration that would achieve the goals of raising awareness and interest in high school students. Only a few teams independently realised they should contact actual high school students and counsellors for input; most simply relied on their own recollections of high school. Most teams identified a dynamic, "real-time" demonstration (as opposed to, say, a slide show or computer animation) as a key requirement. All the teams who consulted with high school students and counsellors also included *interaction* as a key feature: a good demonstration was one that involved the audience directly. (By the end of the semester when all the teams had presented their work, the entire MEC723 class agreed that interaction was very important. The instructors used this point to highlight the importance of customer input in the closing session of MEC723.)

We then instructed the teams to list principles of engineering that could be demonstrated easily and in an interesting manner. Most of the teams' ideas in this regard were quite conventional: gyroscopes, robots, photovoltaic and steam-based power generation, etc. Even though the instructors advised them of several more bizarre possibilities (e.g. non-Newtonian fluids), none of the students considered such ideas in their designs – the reasons for this are not known. They were also told to try to combine as many different principles as possible into their final concept.

Once this initial stage was settled, the student teams became much more comfortable with the project and proceeded to design their apparti with the usual enthusiasm and attention.

At the end of the semester, when the students submitted their reports and presented their designs to the rest of the class, the authors found that the projects could be grouped into three broad categories. First were the few truly exceptional designs, which integrated quite seamlessly a number of engineering principles into a dynamic and interactive demonstration. Next came those who, though they executed the project well, showed either a lack of interest or capacity to think creatively about the particular problem. Finally, there was a small group of teams who simply did not understand what it took to engage and instruct their audience.

After the oral presentations, the authors and the industry representative chose two winning designs, based on criteria of technical merit, feasibility, and the ability to capture the interest of secondary school students. These teams were invited to construct their devices during the Christmas break (2001) and Study Week (2002). As this was extracurricular work for students, participation was strictly voluntary and students were reimbursed for their expenses and paid a modest hourly wage for their time. The authors secured funding from the McConnell Foundation, which sponsors projects involving community work by students and academics. The two winning designs are briefly described below.

4 The winning designs

One project challenged the secondary school audience to consider the requirements for passenger protection in automobiles. A high school teacher was present as well. Ryerson students and one of the authors (Short) made the presentation. They were given a brief introduction to "crumple zones" and how impact forces are transmitted through an automobile structure. This was demonstrated with a pre-built car. The high school students observed the behaviour of the "occupant" during the impact tests; the occupant was an egg. Then, the students were told to build small crash-worthy cars from prepared kits consisting of popsicle sticks, small wooden wheel assemblies, and white glue guns. The high school students were divided into eight teams of four students. After instruction by the Ryerson student presenters, the teams built their cars and then subjected them to crash tests into a barrier. The barrier was part of the demonstration apparatus, constructed by the Ryerson team. Each car carried a raw egg “occupant”. Successful designs were those that prevented the egg from breaking.

The student audience was very enthusiastic. The demonstration session, originally scheduled for 50 minutes, was finally terminated after two hours. The high school teacher that was present asked to borrow the apparatus for his own classes. The Ryerson student presenters were gratified to see that their work was so well received both by the students as well as the instructor. Most significantly, the Ontario National Engineering Week Steering Committee has sought and gained the permission of the Ryerson students to duplicate the crash car demonstration in future years, as a “standard” demonstration for high school outreach. This more than anything speaks to the ability of students with relatively experience to “think outside the box” and create interesting and viable solutions to unconventional problems.

Photographs from the competition at the high school are included at the end of this paper.

The second project involved the construction of a remote controlled unicycle that would balance itself. It would be used to demonstrate gyroscopic effects, coriolis acceleration, etc. Outrider wheels were attached in front and behind the main wheel to provide stability at low speeds and to prevent the unicycle from tipping when banking to turn. The batteries used to power the control system and steering mechanism were also used as balancing weights. The unicycle is steered by simply banking in the direction of the desired turn. The entire device is just over 20 cm long. High school students would be allowed to try to guide the unicycle through a simple obstacle course. The technical complexity of this project was substantive. The authors and even the industry representative attending the oral presentations were not confident the team would be able to build the device. Still, due to the inventiveness and enthusiasm of the team, the authors decided to allow this team to try to build their design.

The unicycle team encountered technical difficulties and was unable to complete their apparatus on time to participate in National Engineering Week. However, the unicycle was eventually completed and is now housed at Ryerson University. In tests, the unicycle performs very well, dispelling the doubts of the instructors. It will be used in future outreach activities. A photograph of the device is provided at the end of this paper.

5 Discussion

The authors found that the work put into the devices by both teams was (a) adequate for the project, (b) slightly overestimated in our budget, and (c) varied widely by group. Funding for the construction phase of both apparati was $5,000 (CAD); about 10% of the funds were left at the end of the projects. The crash-car team completed the project with roughly equal participation by all members. The unicycle project evolved into essentially a one-person effort. Though the students were grateful that some payment was available for their work, the possibility of making money from this work did not affect their desire, or lack thereof, to participate. The authors were quite surprised by this.

We do not believe we can sustain the development of these devices in future years as a project for *all* the students in MEC723. Indeed, some students in the class were unsure how this kind of outreach work could contribute to their capacity to do “real” engineering work. We found that the students most interested in the project were those with the broadest sensibilities and interests. Those who had already set career plans (e.g. to enter the automotive engineering industry) had relatively little interest in the project. Since students' interest impacts their performance, we must adjust our teaching goals accordingly.

We also noted that many of the designs were not very interesting, or not feasible given the cost and time constraints we had put on the project. It is not clear if the relatively low quality of these projects was caused by, or was the cause of, the lack of interest.

Therefore, in the future we intend to offer this kind of outreach-based project as one of many possible projects, from which student teams will choose. Students who are so interested can create other demonstration devices, while also offering more conventional, "industrial" projects for students not interested in this outreach activity. This will constitute a minor but important change to our curriculum. It will provide much needed flexibility for students with different styles, capabilities, and interests to express themselves and use their engineering education in substantive ways.

Finally, the authors will prepare a package describing the structure and administration of this project and make it available to other Canadian engineering schools through the Canadian Design Engineering Network (http://www.cden.ucalgary.ca), to assist other instructors who wish to implement similar projects.

There have been many benefits from this project. The Faculty of Engineering and Applied Science at Ryerson has strengthened its linkage to the PEO and the organisers of National Engineering Week – a linkage that the Faculty will certainly take advantage of in the future. Our outreach activities have been improved noticeably; this should raise awareness of engineering in the community and help attract outstanding secondary school students into Ryerson's engineering programs. The Ryerson students who participated in the outreach program developed a much keener sense of the role of the engineer in the community and the difficulties associated with teaching engineering (something students rarely consider). Also, the secondary school students who participated in the demonstration gained a substantially deeper understanding of the complexity of engineering. All in all, the experience was beneficial to everyone involved.

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Photographs

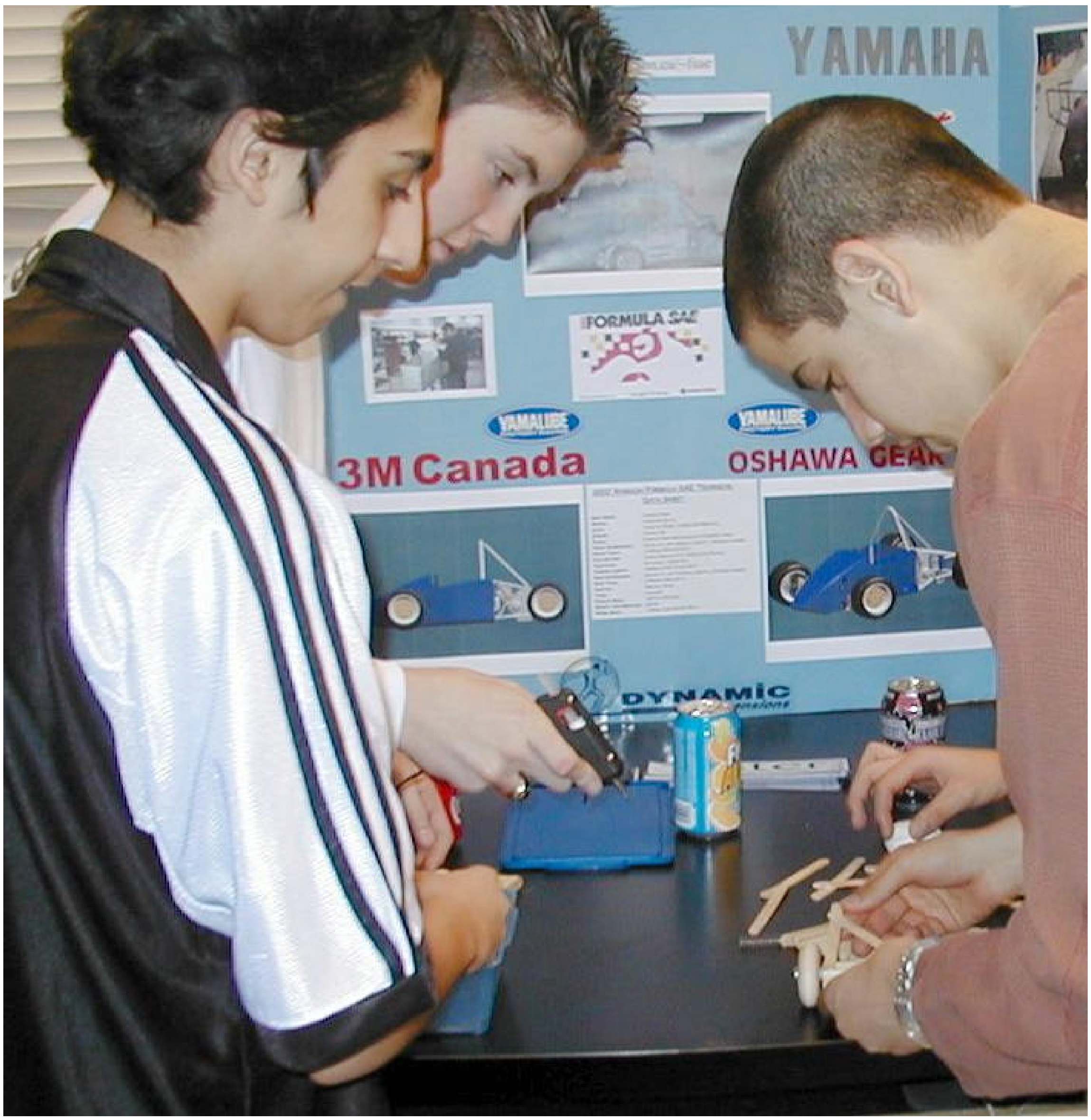

Figure 1. High school students constructing a "crash cart".

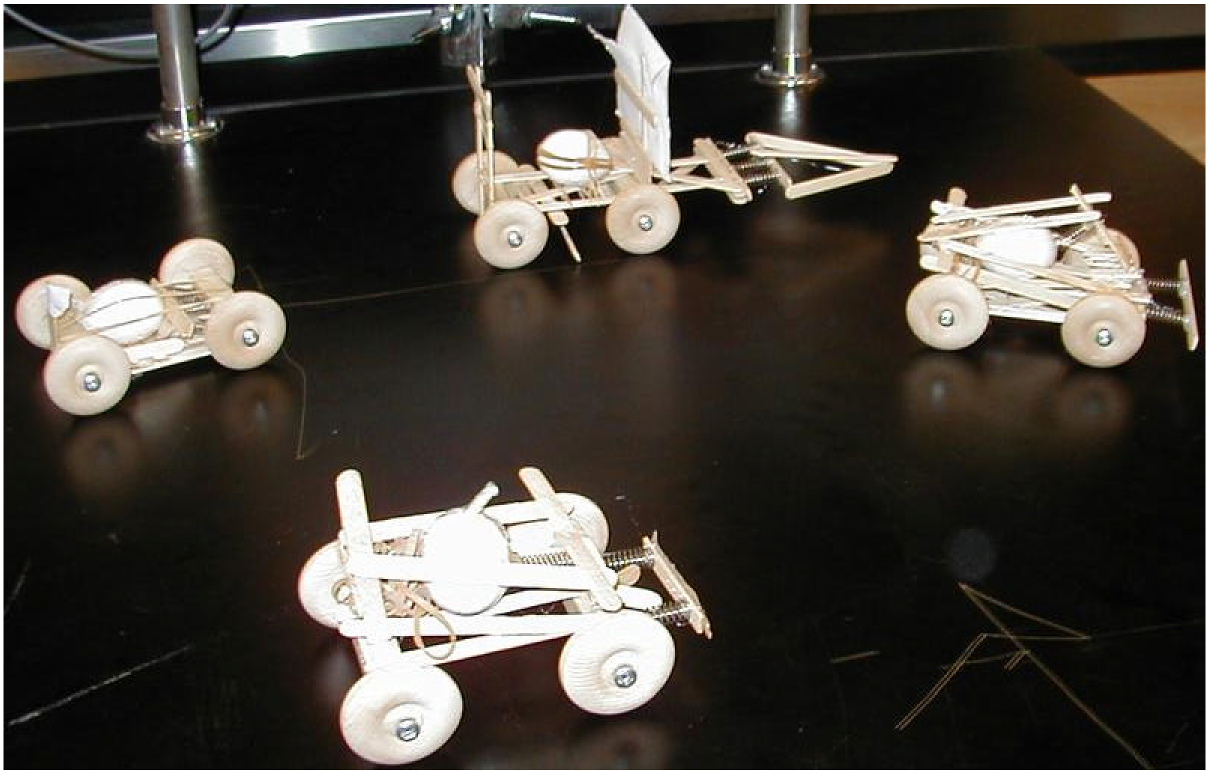

Figure 2. Four of the “crash carts” constructed by high school students.

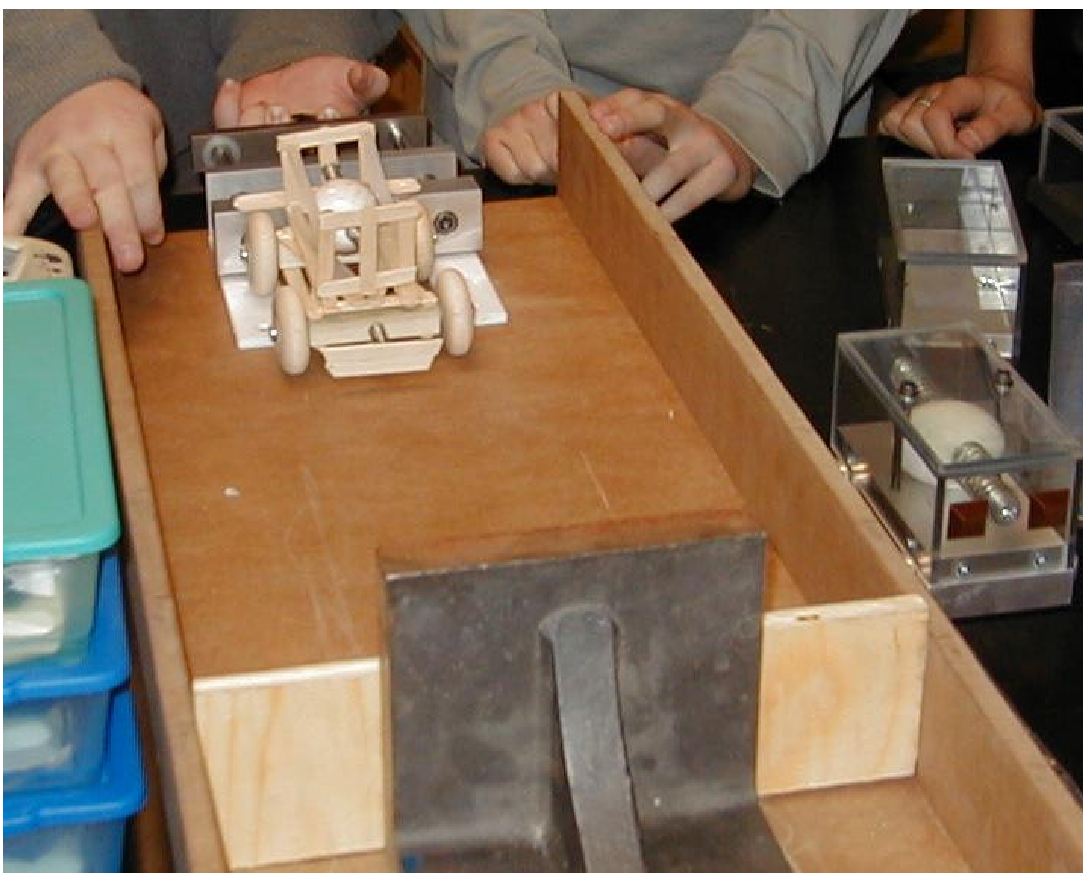

Figure 3. A cart in the launch mechanism, ready for testing.

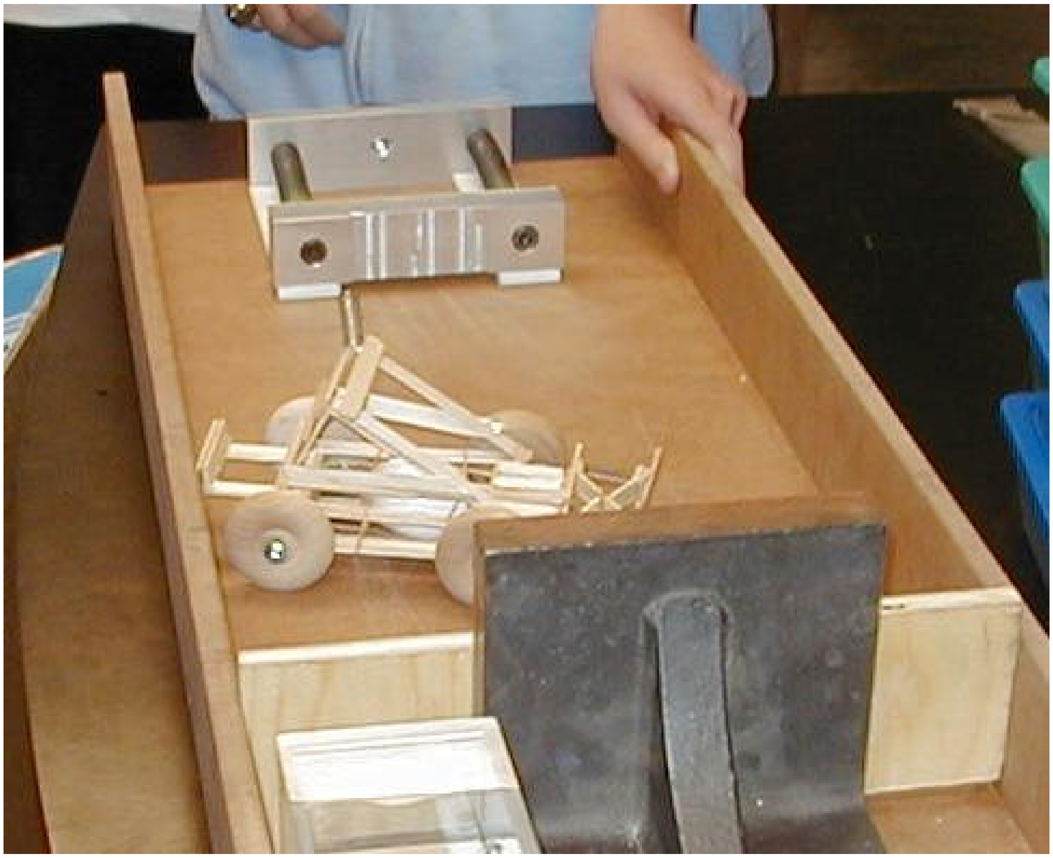

Figure 4.   A successful test, after impact on the barrier.

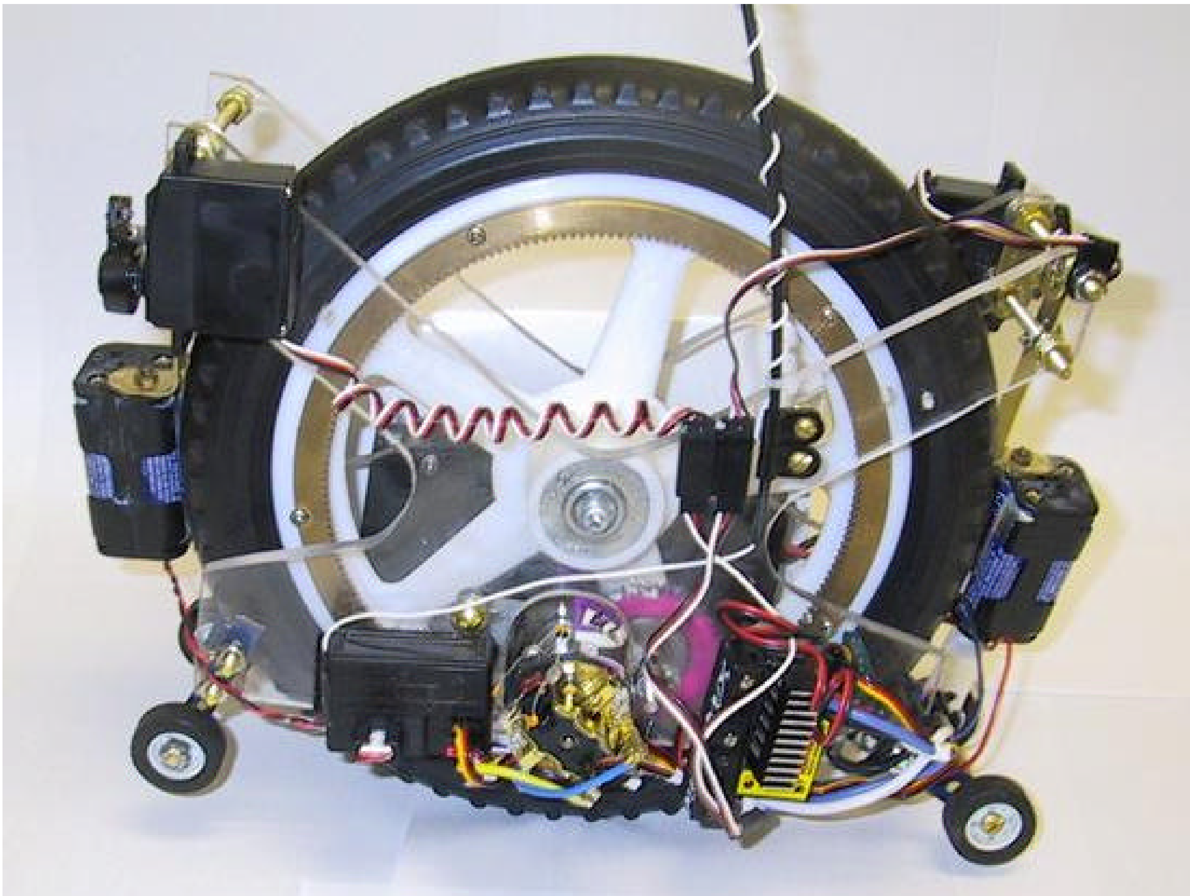

Figure 5. The remote-controlled unicycle demonstration device.

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