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Design and Build at Home: Development of a Low-cost and Versatile Hardware Kit for a Remote First-year Mechanical Engineering Design Class

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I. Introduction

Engineering design courses with hands-on laboratories are a critical component of an engineering undergraduate curriculum. In particular, incorporating design courses early has been shown to help with retention rates in engineering, as well as with improved ability of students to solve open-ended problems [1, 2]. These courses have also shown student progress in academic achievement by helping to build confidence in their engineering skills, and by expanding their perspective on problems and solutions [3, 4]. Introduction to Engineering Graphics and Design is an introductory level course, usually taken by first and second year university engineering students at University of California, San Diego. In addition to lectures, which provide content addressing a range of engineering design and analysis topics, the in-person course consisted of two hands-on projects. The first project was completed individually and was designed to introduce students to the main engineering skills – including basic CAD, shop tools, and analysis techniques – that they would need for the rest of the course. The end-of-quarter robot design project was completed in teams and was designed to test the students' learned ability in design, manufacturing, and engineering analysis. Students were provided with various building materials, as well as with access to a design studio with machine shop tools, laser cutters, and 3D printers. Students were graded on their robot's design and performance, and they were assessed at various milestones throughout the quarter. A technical report that described the robot and provided an analysis on its capabilities, was required upon completion.

Unlike many undergraduate engineering courses, this course was designed for students to both gain knowledge in engineering theory, as well as to acquire design experience in a hands-on team setting. When classes were transitioned to operating in a fully remote setting, the instructional team decided to develop a hardware kit to enable an at-home version of the design course. Through a competitive application process, we received an instructional improvement grant from our institution that allowed us to develop, purchase, and send the kits prior to the start of the course, as well as redesign aspects of the course so that students would have learning experiences that were comparable to the in-person version of the course.

Applying backward course design principles [5], we first revisited our course learning outcomes (what we wanted students to know, value, and be able to do by the end of the quarter). Our course learning outcomes included both cognitive goals – such as being able to identify design problems and design a system to meet the desired needs – as well as affective goals – such as displaying effective teamwork and forming an engineering identity. While some of the learning outcomes would likely present unique challenges in a remote instructional environment, ultimately we decided they were all essential, regardless of the course format. Another important aspect of backward course design is considering who our learners are and the unique knowledge, backgrounds, experiences, and resources they bring to their learning. We learned from teaching fully remotely in the prior quarter that the differences in students' access to educational resources that would enable them to be successful in a remote environment were vast. For example, many students reported not having reliable access to the internet or even places to work without interruptions or distractions. In both our design and teaching of the course, we kept these resource disparities in mind and did our best to be flexible and supportive. We also kept this in mind when designing the tool kits and made no assumptions about the resources students would need to complete their projects.

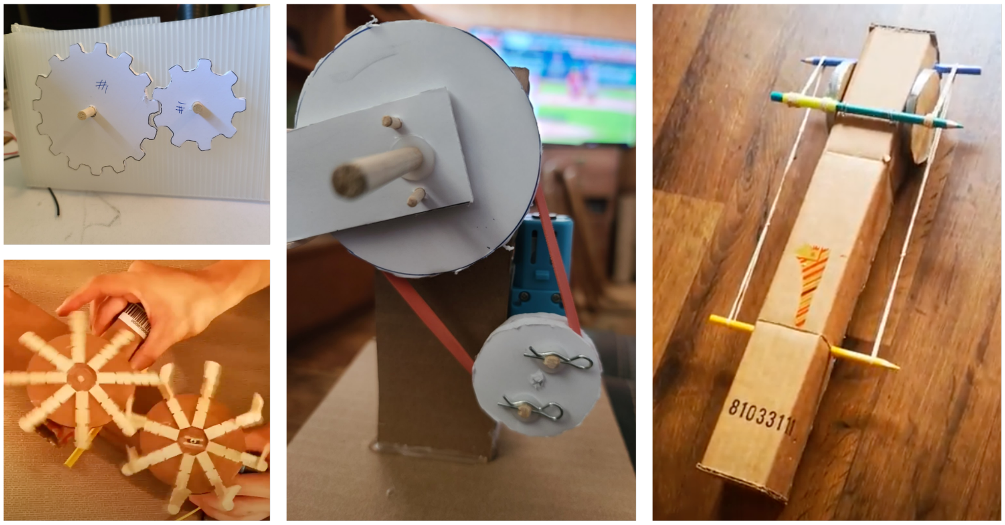
The next step in backward course design is developing assessments that align with course learning outcomes. As in the in-person version of the course, the individual and team projects remained essential to our ability to assess student learning and continued to be a significant portion of students' overall grade. Readings, assignments, and exams were also included in our assessment activities and were integrated with the intention of supporting students' ability to successfully complete the major projects. Deciding that our assessments would remain fairly consistent with our in-person version of the course, the final step in our course design was examining which teaching methods and strategies would need to be modified and in what ways. Following is a detailed description of the hardware kit development process, implementation of changes we made to the course, and an analysis of the efficacy of the hardware kits and course changes in meeting student learning outcomes.

II. Hardware Kit Development

The original course promoted creativity and helped students gain experience in design and CAD, since they were required to fabricate all their own parts for their robot. When looking to send hardware kits to the students, we did find that numerous off-the-shelf kits with pre-shaped plastic pieces and connectors were available. However, many of these kits had a specific goal in mind and would not provide the flexibility the students needed, nor promote the creativity and engineering design skills desired. There was a possibility that students could modify the store-bought kits to their needs, but the tools required to accomplish this task would be unsafe for a remote setting. Since students would be working in their own homes without supervision, the tools sent in the kits needed to be relatively safe and easily explained. Store-bought kits also posed a cost problem and would not provide enough material for the students to build a complete robot, while remaining within the budget. Finally, it would have been difficult to achieve the learning objectives of the course with a store-bought kit. Design for manufacturability, teamwork, basic fabrication techniques, and use of engineering analysis needed to be considered when designing the robots. The store-bought kits would have been too simple to work with and still achieve these outcomes. These requirements led the team to develop a custom hardware kit as explained below.

A. Content Development

The creation of the kits began with extensive prototyping and testing of candidate components during the summer before the remote course was to be offered. The first round of prototyping focused on identifying potential tools that could be used by students remotely, as well as on candidate materials that were easy to work with, yet strong enough to be used for structural components of the robots. These tools and materials were used to create a number of functional components – including gears, pulleys, basic drivetrains, and linkages – that are typically made by students in the course. These fabricated components (see Fig. 1) were then tested and evaluated based on their effectiveness, ease of fabrication, and durability, and other notable features or difficulties were tracked as well.



(a) (b) (c)

Figure 1. *Examples of prototypes created during kit development phase. Candidate materials and tools were used to fabricate (a) gears using foamcore and popsicle sticks, (b) a 1-degree-of-freedom arm driven by belt and pulley system, and (c) a simple car using a friction-drive mechanism.*

Throughout the testing process, we noticed that while many of the ideas and creations worked as intended, the fabrication processes were often tedious, or the components did not have the desired tolerance and/or durability. As a result, the team decided that the kit should include both materials and tools that would enable students to design and fabricate completely custom components, as well as a few more durable and tightly toleranced components. This set of functional components would be laser cut from acrylic and could help address the shortcomings noticed in testing, while remaining feasible to include in all hardware kits.

Another aspect of testing focused on selecting and sourcing methods for controlling motors. Some proposed ideas included a chip with USB connections that could be controlled using a computer, a stand-alone remote controller and receiver chip, and even a remote-controlled toy that could be disassembled for parts. The first option, although feasible, would require too many additional topics to be taught, including basic programming, and would require the robots to be constantly tethered to the computer. The latter two options were tested, and both performed well when connected to some basic robot prototypes. Ultimately, the hardware kit used the standalone remote controller and receiver chip for its lower cost and lower workload for students, since it would not require students to reverse engineer an existing RC toy design just for the controller hardware.

B. Final Kit

In order to satisfy all learning objectives and to replicate the student experiences from the in-person version of the course, the hardware kit consists of a range of purchased and in-house manufactured components. The components can be divided into the following categories: tools, structural materials, custom-manufactured parts (including laser-cut acrylic pieces and 3D-printed parts), energy sources, electronics and power components, and fasteners and other hardware. The final kit components can also be seen in Fig. 2.

Tools: The tools provided in the hardware kit are particularly important and dictate the feasibility of various designs that students envision. The kit essentially replicates the smaller, portable tools found in the on-campus design studio and adapts them to the remote classroom setting. Items such as safety glasses, a small vise, and a rubber cutting pad were included to provide added convenience and safety for students. Small tools such as cutting blades, hand-held jewelry drills, sand paper, hot glue guns, glue sticks, and screwdrivers provide students the ability to remove, join, and assemble materials in nearly any environment. In particular, the cutting blades also aim to replicate the use of laser cutting, as students can use the technique to create 2D, planar parts by printing (or tracing on a tablet) a PDF version of their CAD design, gluing it to the cardboard or foam core, and cutting it out. As a result, the available tools heavily influenced the choice of structural materials to include in the hardware kit.

Structural Materials: The main goal of the structural materials is to be workable in a remote setting with only the provided tools. The major structural materials were chosen to be printing-paper-sized corrugated cardboard and laminated paper foam core since they both exhibit good stiffness and strength, while being inexpensive and workable with minimal tools. They can easily be reshaped, drilled, and joined together. Wooden rods and popsicle sticks form another major portion of the structural materials, and were chosen for much of the same reasons as before. In addition, these wooden parts offer greater durability and improved performance in non-static applications. However, while these structural materials are easy to work with, they still have limitations due to material properties and the available tools.

Custom Components: To address these shortcomings, the hardware kit utilized custom pieces, standardized across all kits, mostly made out of laser-cut acrylic. These components were either deemed too intricate to fabricate using hand tools, require high tolerances, or would be unnecessary busy-work that would contribute little to the learning objectives if students were to make them by hand. The parts include a gear set with 3 diameters, adaptors for motor output shafts, base pieces, arms, motor mounts, collars, clips, as well as an escapement wheel and pallet for a pendulum clock. All of the parts above have intricate profiles and/or precision for holes and slots that cannot be achieved easily by hand. The holes and slots come in 4 sizes, and were sized to have clearance for some fasteners, light interference with other fasteners, and also allow for a fairly close fit for rotating shafts. It is also worth noting that while many of these acrylic pieces were designed to serve a single purpose, they can be used successfully in many different scenarios.

Energy Sources: In order to have motion, energy is a necessity. As a result, the hardware kit includes a number of potential sources of energy that students can make use of when creating their robots. The component of choice for most robots tends to be DC motors, and two were included in each kit. The two motors intentionally had different gear ratios and provided different stall torques and no-load speeds. In addition, the kit contains more creative sources of energy that students can take advantage of, including springs, rubber bands, and perhaps even the gravitational potential energy of the hardware kit itself.

Electronics and Power Components: Electrical hardware, such as the battery holder, wires, and

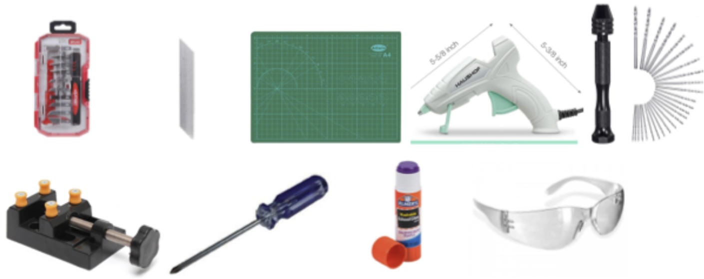
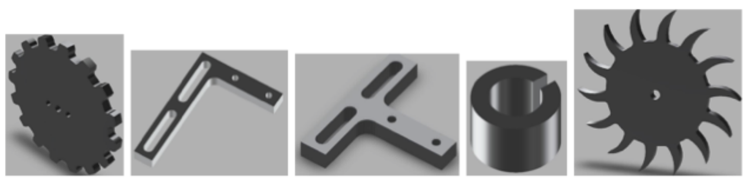
Box		• 12x10x8 inch shipping box
Tools		• Exacto blade kit • Saw blade • Cutting mat • Hot glue gun • Hand drill and bits • Vice • Screwdriver • Gluestick • Safety glasses • Sandpaper
Structural Materials		• Foam core (3 8"x10" sheets) • Cardboard (4 8.5"x11" sheets) • Wooden dowels (¼" and 3/16") • Popsicle sticks
Custom Acrylic Parts		• Gears (4", 3", 2") • Motor mounts • Clock escapement wheel, pallet adaptor, shaft sleeve, nut holder • Shaft adaptors • Jig
Energy Sources		• DC Motors (2x) • Rubberbands (2x of 3 types) • Extension springs (2x)
Electronics / Power		• Battery holder • AA batteries • Motor controller and receiver chip • Wires
Fasteners and other hardware		• Washers (M8, M6, M4, M3) • R-clips • Plastic rivets • Rubber strip • Nuts • Screws • Fishing line • String

Figure 2. *Final kit parts shipped to the students.*

the remote-controller and receiver chip are all essential for robot functionality. To provide the required DC power for all electrical components, each hardware kit also contains 6 AA batteries.

Fasteners and Other Hardware: Finally, the kit materials cannot work as a whole without proper fasteners and other mechanical hardware. Bolts, nuts, and washers enable assembly and disassembly. Additional fasteners, such as rivets and cotter pins, can improve assembly efficiency in some scenarios and are also included.

It should be noted that many kit items can serve multiple purposes for different designs, and selecting components with this ability was important. In fact, the lines drawn between the categories defined above are perhaps less clearly defined in reality. Many items find use in a variety of scenarios, even ones unanticipated by the instructional team. For example, wooden rods may be used for structures, as rotating shafts, or even as fasteners. Rubber bands provided energy and power for some robot designs, while other designs used them as functional components, such as drive belts or simply as a source of higher friction. The hardware kit was designed with this idea of making components multipurpose in mind, so as to reduce the overall number of components, while still providing sufficient resources to promote out-of-the-box designs.

C. Creation, Assembly, Distribution

After extensive testing of candidate components and finalizing the kit list, items were sourced, purchased, and shipped to a single location to be packaged. Simultaneously, the custom-manufactured pieces were fabricated in-house. In parallel to the purchasing and manufacturing, preliminary packing began as soon as components were fabricated or delivered. The small, loose items (such as nuts, bolts, rivets, etc.) were sorted and bagged for individual kits in preparation for the final packing. Once a sufficient number of major kit components was ready for packing, an assembly line with a number of stations – including one for making shipping boxes, one for adding a variety of kit items to the boxes, and one for final preparations for shipping – was created (Fig. 3). After all kits were assembled, they were shipped to each student's address with appropriate shipping labels. Most students who took the course resided in the United States, but a few kits needed to be shipped internationally. The process of physically constructing the hardware kits and final shipping lasted approximately 6 weeks.

The most uncertain part of this process was ordering items from online. The majority of the kit components were from Amazon or McMaster Carr, with a few items (mainly electronics) sourced from elsewhere. With the limited time available for creating the kits, sourcing items reliably became a main concern. For the Amazon purchases, due to the small scale of many vendors and Amazon storage logistics, suppliers sometimes did not have sufficient quantity in stock to satisfy our demands for the hardware kit in the short time frame. Furthermore, many of the electronic components in particular needed to be shipped from international locations, which required additional time for those components to arrive. In general, buffer times should be budgeted for the lack of supplies and long shipment times.

In contrast, the most labor-intensive aspects of the hardware kit were the in-house manufacturing, as well as sorting loose items for preliminary packaging. The laser-cut acrylic pieces were fabricated using two laser cutters, which were run simultaneously for roughly five to six hours per day over approximately one week. The in-house manufacturing heavily relied on the smooth operation of the machines, and initial technical difficulties with the laser cutters caused a significant delay in the progress. In addition, the other aspect of the kit preparation that required significant effort from those involved was preliminary packaging. This included opening shipments of small, loose items such as bolts, nuts, washers, etc., as well as cutting or trimming items like wires and strings, before separating them into bags that go into each individual kit. This process is arguably the most tedious step, although there is generally little risk involved.

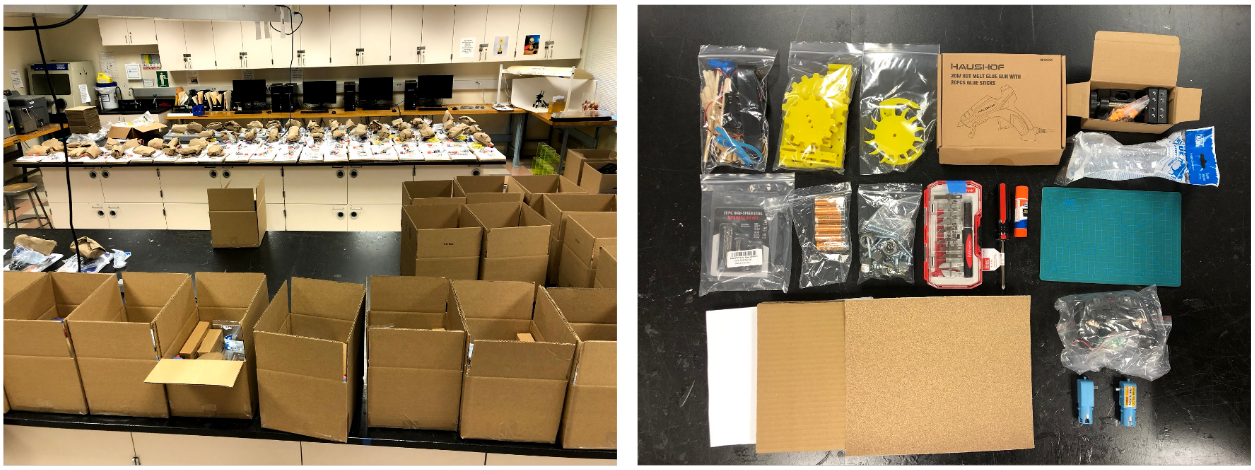


Figure 3. *Final assembly of the kits included packaging small, loose components into bags and finally packing everything together into the shipping boxes.*

The final assembly took place with 5 to 6 people packing kit items into shipping boxes over the span of 2 days. The boxes were 12 x 10 x 8.5 inches, and had a reasonable amount of room to spare with all kit components inside. The empty space was filled with wrapping paper to reduce the likelihood of damage, and little to no damage was reported from shipping. Each kit, ready for shipment, had a mass of approximately 6.3 lbs, and was shipped to its final destination through Fedex. Most domestic US shipments arrived within 3 business days or so, while the international shipments were shipped at an earlier date to account for the longer shipment time.

III. Remote Projects Enabled by Hardware Kit

The two main course projects – the clock project and the open-ended final robot project – were updated to accommodate the remote setting and new hardware kit. The goal was to provide the students in the remote course the opportunity to achieve as many of the same learning objectives as in the in-person course. The updated projects that were enabled by the new hardware kit are detailed here.

A. Clock Project

The clock project is completed by each student, individually, and is designed as a way to introduce students to both the hands-on skills, as well as the basis for the analysis techniques they will need for the quarter. The clock itself is a simple pendulum clock with an escapement mechanism, and the project involves CAD and fabrication, along with analysis and comparison of the theoretical performance of their individual clock with the actual measured performance. An important aspect of the project is that students are able to independently design the shape and aesthetics of the pendulum portion of their clock, fostering creativity. This project is the students’ first opportunity to learn CAD, as well as to learn how to use any tools and fabrication methods needed for the rest of the course.

The main hardware components of the clock include a stand, pendulum, escapement wheel, rotating shafts, and acrylic fasteners. Based on what could be fabricated using the new hardware kit, the single piece acrylic clock stand was replaced with a boxed cardboard stand and base. Testing found that aligning the rotational shafts of the pendulum and escapement wheel, which is critical for correct clock operation, was very difficult. Therefore, a template with pre-aligned holes was provided for the students to cut out and glue to cardboard. This process introduced students to the hobby knife set and the hot glue gun, as well as to an important technique for using a template to create precise components. This technique would prove valuable for their robot project when they would be working in teams, remotely, and would need a method for passing ideas and specifications to each other without ambiguity. The aluminum rods were replaced with wooden dowels for the pendulum and escapement wheel rotational shafts. Students were instructed to cut the provided wooden dowels to a given length and drill holes at precise positions, recreating the rotational shafts, and creating fastening points on those shafts for other components. This process introduced students to the small saw and drill they could use to modify the dowels. Testing found that shafts inserted into a cardboard clock stand would cause wear from normal, repeated use, so nylon washers were added and glued onto the holes. Retaining clips were used to fasten the wooden shafts into place, replacing the set screws in the original clock. The fastening and reinforcement techniques would be important for robot construction as well.

The most important aspect for the clock project was the correct operation and timing of the pendulum and escapement wheel. Test parts were constructed out of foam core and cardboard, however, even with a template, the construction of these pieces proved to be laborious and imprecise, making acrylic the best option. Because pendulum design affected the timing of the clock and enabled students to be creative, students were still required to design their own pendulum. An acrylic pallet adapter that attaches to a foam core pendulum was created. The custom pendulum design could then be glued to the foam core, cut out, and attached to the pallet adapter with bolts. The final assembly changes included creating a foam core pulley mechanism that would provide the clock with potential energy to maintain rotation. A sample clock was constructed, and testing showed that the clock operated normally with the same approximate error as the original clock project. Example clocks from students in the remote course can be seen in Fig. 4.

B. Final Robot Project

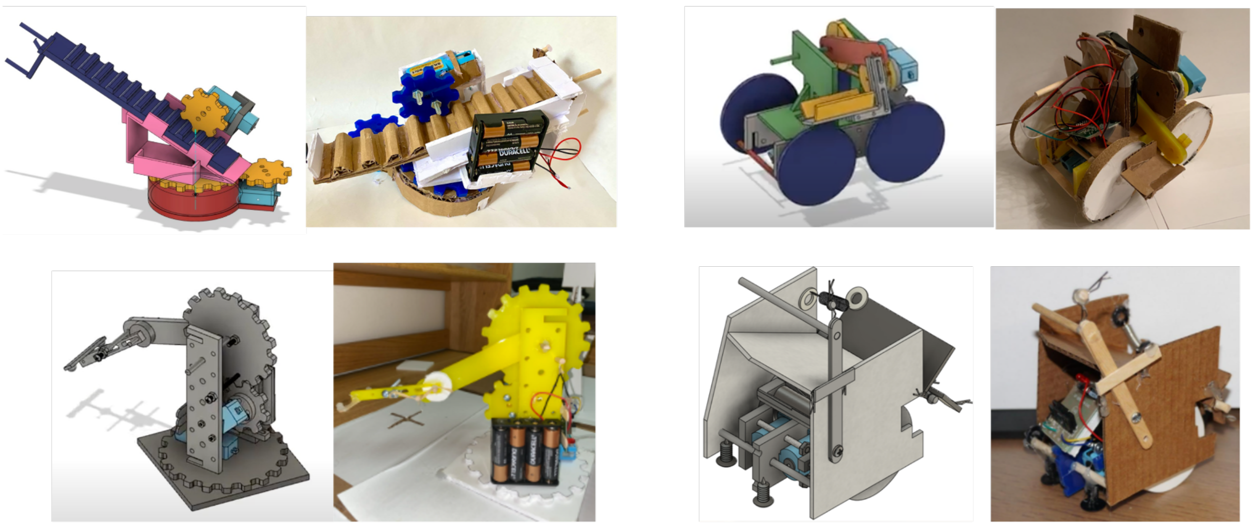
During the second half of the quarter, students work in teams to complete a final robot project. There are a number of milestones that each team must reach, and the project culminates in a class-wide robot contest, where the teams compete head-to-head. Several aspects of the project and associated assignments were redesigned to accommodate the remote learning environment and new hardware kit. First, because students could not meet to work on a robot together in-person, and because of the importance of the hands-on experience, each student was required to fabricate his or her own physical robot, rather than submitting one piece of hardware for the entire team. Learning to work on a team and manage a project were still critical learning objectives of the course, so students still worked on teams to design a single robot. However, each student was then individually responsible for the fabrication of the team's design. Teams were ultimately given a single grade based on the best performing robot and were offered bonus points if they were able to demonstrate multiple working robots within their team. These decisions were made in

Figure 4. *Examples of pendulum clocks fabricated during the remote version of the course in the Fall of 2020. Students were still able to customize the design of the pendulum itself, as shown here.*

order to strike a balance of meeting learning objectives, while also understanding the difficulties of hardware and fabrication at home. The second significant change was that each student had to fabricate his or her own robot playing field. Students were given instructions for how to turn the cardboard shipping box (originally used to send their hardware kit) into the playing field. Step-by-step instructions were also provided for creating the "game pieces" required for the robot contest. The theme was the popular game, Animal Crossing, and the robot was tasked with picking "fruit" off of "trees" on the playing field and placing them into a small bucket. The fruit and trees were also fabricated using materials from the kit, and students were encouraged to decorate and customize their field, as seen in Fig. 5.

Figure 5. *Each student was required to fabricate their own playing field based on the given instructions. They were also encouraged to customize it, as shown by one student example here.*

The hardware kits sent to each student enabled them to fabricate their own robot for this final contest. Unlike the clock project, where there were step-by-step instructions and every student used the same set of components from the kit, the robot project is designed to be open-ended. Ideally the kit parts would enable students to be creative and would allow them to design and fabricate a range



(a) (b)

Figure 6. *Examples of robot CAD and physical hardware during the remote version of the course in Fall of 2020. The hardware kit enabled different robot architectures and creative mechanisms, including examples of (a) stationary robots with a 1-degree-of-freedom arm and (b) wheeled driving robots. Two example robots are shown for each case, highlighting the wide range of student designs and significant creativity.*

of different mechanisms and overall designs. In addition, given that only two motors (with different gear ratios) were included in the kit, students were forced to think carefully about how to best use these energy sources. As seen in Fig. 6, students were able to create robots with very different architectures, based on two main strategies for the contest. Some teams created a stationary robot with a rotary base and a 1-degree-of-freedom arm (Fig. 6(a)). The mechanism for the arm itself varied widely, including a rack and pinion, pulleys, and gears. On the other hand, there were teams who chose to create a wheeled, driving robot (Fig. 6(b)). Some of these robots were driven by two motors, in which case, they could move in two degrees-of-freedom on the playing field, but were forced to either have a passive arm or to use alternative energy sources, like the rubber bands. For teams that chose to only use one motor for their drive train, they could only move along a single direction, but they were then able to use the remaining motor for a 1-degree-of-freedom arm.

There were several unique, clever mechanisms designed and fabricated by the students. In particular, the team that won the final contest created an arm that could be folded and held in place to meet the starting size requirements, along with a mechanism that would release the arm and allow it to unfold to the length required to reach the fruit on the trees. They then used one motor for the rotation of the robot base and the second motor to tip the collecting arm backwards to dump the fruit into the basket. A time series of this robot can be seen in Fig. 7 and is just one example of the creativity and ingenuity enabled by the hardware kit.

It should be noted that in addition to the design, fabrication, and testing of the robots for the final project, students were also required to perform analysis on a component of their particular robot. This analysis had to include a free body diagram, along with either a force/torque analysis or speed analysis to calculate the maximum performance. Students then had to perform an experiment to measure the actual performance and compare this to the theoretical values, including a discussion on any discrepancies and design limitations.

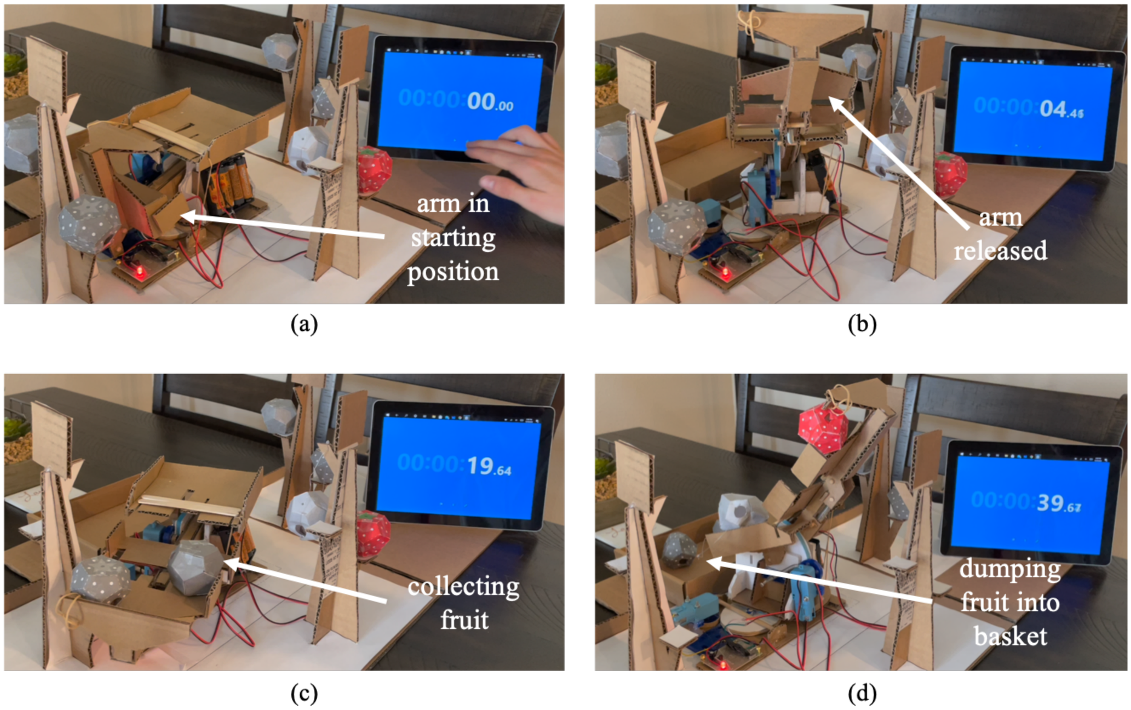


Figure 7. *Time series of the winning robot created using the new hardware kit during the remote course in Fall 2020. (a) The robot started with the arm folded to meet the dimension requirements. (b) The arm would release, becoming long enough to (c) collect the fruit from the trees. The base of the robot would rotate to collect the fruit, and the arm would also lift to (d) dump the fruit into the basket to score points.*

IV. Hardware Kit Assessment

A. Student Survey Results

At the end of the quarter, an online survey was sent to all students in the course. The survey contained a mix of both qualitative short response questions, as well as more quantitative questions that asked students to rate various experiences on a Likert scale. Out of 91 students in the course, 69 students completed the survey and responded that they would be willing for their answers to be used for research purposes.

As seen in Fig. 8 (middle), 73.9% of students that responded thought that the hardware kit had a positive or significant positive contribution to their ability to learn in a remote environment. Similarly, 81.2% and 73.9% said that two elements of the course enabled by the hardware kits – the open-ended robot project and lab activities – respectively, had a positive or significant positive contribution to their ability to learn remotely.

Students were also asked a series of questions specific to their experience working with the hardware kits. On a scale from 1 to 7 (1 = not good and 7 = excellent), students rated their overall experience very highly, as seen in Fig. 9 (top left). Students also thought that the kit itself was very well-suited for the course projects (Fig. 9 (bottom left)) and they were generally satisfied with the material allocations/quantities provided (Fig. 9 (bottom right)). When asked to follow up with more details on the kit materials themselves, several students mentioned that it would be beneficial to include more cardboard and foamcore so that they would not have to conserve and

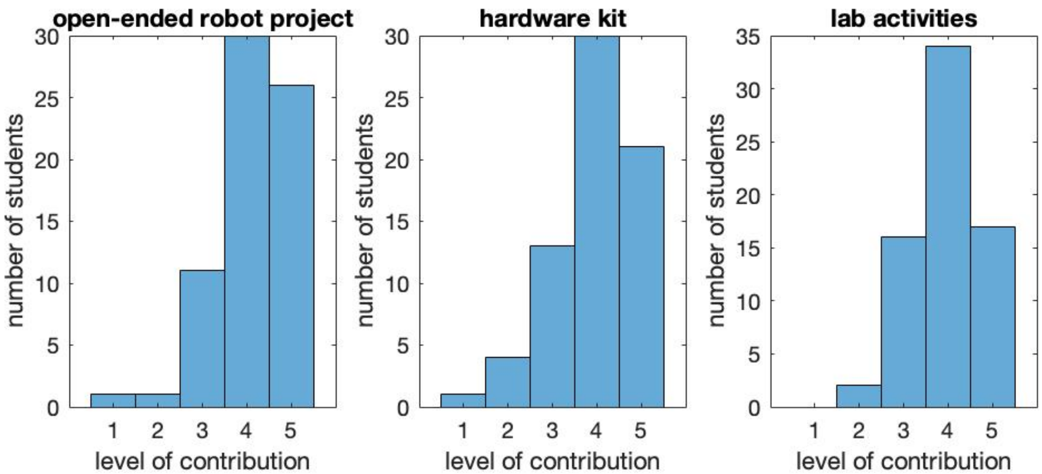


Figure 8. *Students were asked to rank from 1 to 5 (1 = significant negative contribution and 5 = significant positive contribution) the level to which several elements of the course contributed to their ability to learn in a remote environment, including the open-ended robot project (left), hardware kit (middle), and lab activities (right).*

could prototype more freely. Many students also responded that they would have liked to have been given more DC motors in their kit. When asked about additional items they would have liked that were not included in the kits, some students suggested tape, a straight edge or ruler, and compression springs. Many students liked the acrylic parts, but would have liked more of them and a larger variety. The most popular acrylic part by far was the D-shaft adaptor.

Finally, the survey aimed to understand the level of difficulty of working with the kit materials. As seen in Fig. 9 (top right), there was a range of responses to the question of the level of difficulty, when rated on a 7-point scale, to working with the kit materials. In particular, many students noted that the drilling, which had to be performed with a manual hand drill, was the most challenging task. It should be noted that the instructional team realized early on that the drill bits included in the kit were of significantly poorer quality than the ones initially tested, and we did provide alternative fabrication options to avoid using the drill bits. In addition, the kit component that gave students the most trouble was the controller/receiver. Specific issues included wires and their connection to the board being too fragile and often breaking, the receiver chip being unresponsive all together, or students accidentally shorting the receiver. Several students reported having to replace this component of their kit during the quarter.

B. Student Teaching Team Survey Results

A survey was also sent to the graduate teaching assistants and undergraduate tutors for the course. The main responsibilities of the graduate teaching assistants included holding office hours, preparing assignments and lab activities, and guiding students on their robot designs and analysis. The main responsibilities of the undergraduate tutors were running one lab section each week, holding office hours, and guiding students on their robot designs and analysis.

The student teaching team was asked about their experience with helping the teams debug their hardware and how that experience compared to any previous in-person experiences. Most agreed that helping students debug was more challenging in this remote setting, mainly due to the need to rely on verbal communication, rather than being able to physically touch and test components

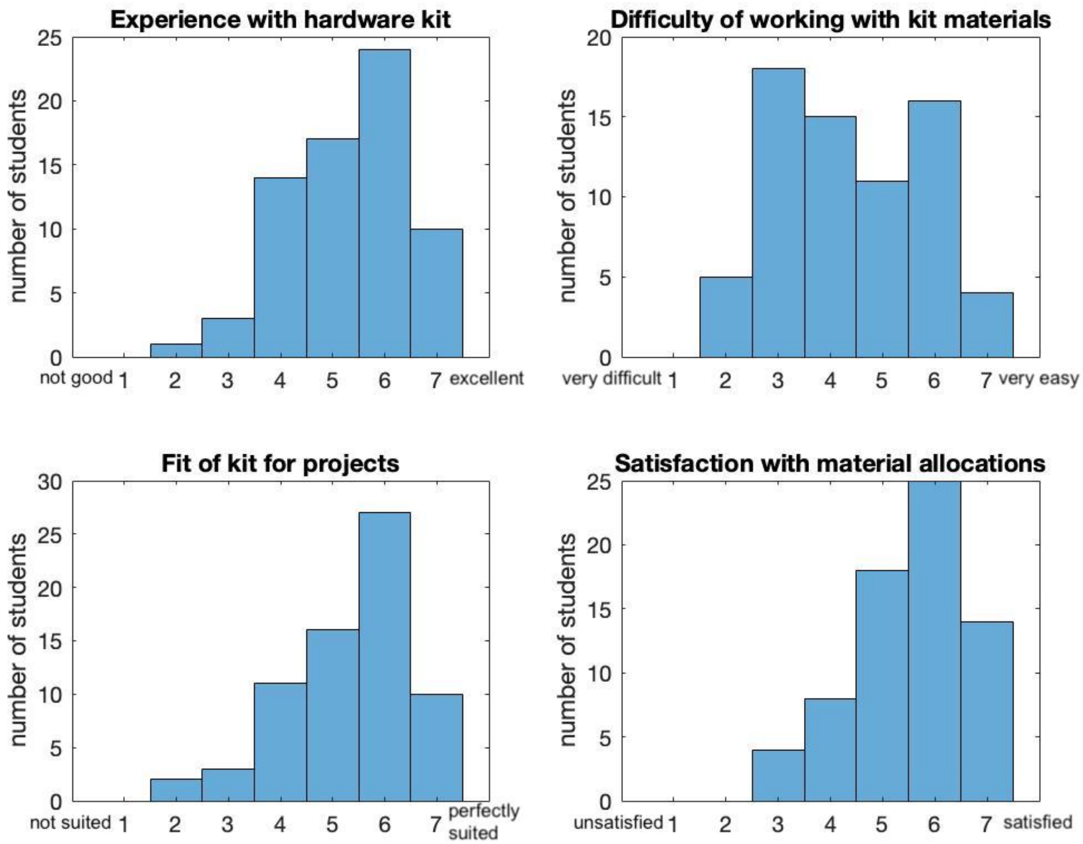


Figure 9. *Students were asked to rate from 1 to 7 various aspects of their experience working with the hardware kit. Results were highly positive in terms of students' overall experience with the kit, the level of fit of the kit for the course projects, and students' satisfaction with the allocations of materials in the kit, but results were more mixed with regards to the difficulty of working with kit materials.*

themselves. Members of the student teaching team explained how identifying the root cause of robot malfunctions tended to be more time consuming, and required them to develop ways to give instructions on what tests the students should try to perform for themselves in order to troubleshoot the issues.

Many members of the teaching team also mentioned that the tutor-student and the student-student interactions were quite different. In terms of the tutor-student interactions, the tutors could no longer simply walk around the design studio and do a quick check on progress. They had to find other methods, including break-out rooms on Zoom, to check in on students and ask them questions in a more private environment. In terms of the student-student interactions, the student teaching team noted that students could no longer quickly turn around and ask a peer for advice – something that is very natural in an in-person setting. Robot project teams also worked in break-out rooms on Zoom, making it difficult for teams to see progress and designs from other teams, which could affect motivation.

Finally, when asked about teamwork, there was a mixed response from the student teaching team. Some tutors felt that because each student had his or her own kit and was responsible for fabricating his or her own robot, there was a significant amount of work done independently. Some tutors saw this trend as positive, since students could push forward on their own more easily if one team member was not pulling his or her weight, while other tutors saw this trend as negative since there seemed to be a bit less collaboration. On the other hand, there were tutors who felt that students having their own kits actually promoted more communication on how they were putting individual components of the robot together.

V. Discussion and Conclusion

Overall, the hardware kits enabled a highly successful remote version of the first year engineering design course. Students were able to still design, fabricate, and analyze pendulum clocks, just as in the in-person version of the course. They were also able to work together on teams to create robots to compete in a head-to-head contest. Students also surprised the instructional team with creative uses for kit parts. And even with a completely new hardware kit with different parts compared to the in-person course, the level of precision and attention to tolerances still made a difference in the final robot performance, just as in the in-person course. Without the hardware kits, many of the learning objectives would have had to have been changed. Based on comments given in the course evaluations, it was clear that students highly valued the hands-on experience and both recognized and appreciated the time and effort that was put into the creation and distribution of the kits.

It should be noted that the development, assembly, distribution, and debugging of the kits would not have been possible without a significant level of support. In addition to the cost of the kits themselves, several undergraduate tutors were hired to help with the kit development and assembly, and both undergraduate and graduate tutors were hired to help with the course itself. The development process also required a significant amount of time and planning prior to the start of the course. Based on instructor observation and student feedback, a few kit updates are currently being made for the next offering of the course this spring, including selecting a different set of drill bits, changing the custom acrylic gears, and swapping the battery pack for one with a switch. Although students were not able to gain experience in the design studio to learn how to use basic shop tools, the hardware kits and associated projects still enabled them to experience the full design process – including design, fabrication, testing, and analysis.

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