K'nex Car Critical Design Review

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Abstract

The purpose of the K'nex car project is to introduce students to fundamental engineering design and applications. As students in the Mercer University School of Engineering, we must build a K'nex car solely using K'nex pieces. Our objective was to design a K'nex car with the greatest efficiency for the Hill Climber event and our client: Dr. Laura Moody. During each round of the Hill Climber, vehicles have to complete by climbing up an incline during a limited time interval. The incline of the hill increases after each round of the competition. We came up with three preliminary design, and we chose design 2 based on the following merit criteria: weight, velocity, and gear ratio. We tested the speed of our final product on various inclinations; we also measured the velocity on varying intervals of time and distance; finally, we tested the load that our final product can carry to prove its strong torque. The tests allowed us to estimate our final design's performance in the Hill Climber event, and how to improve our design according to potential deficiencies that could occur during the competition. We modified the design by switching the two large gears with rubber bands (as front wheels) to two large black wheels because of its curvature during the speedtest by using the competition apparatus. During the Hill Climber, our vehicle successfully completed the earlier stages of the competition; however, on the last round, our vehicle lost the championship due its dearth of speed compared to our opponent.

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1. Introduction

1.1 Purpose and the Objective of the Project

The purpose of the project is to introduce fundamental engineering concepts to the students by giving them the opportunity to work with a client, just as in a professional situation. The objective of the assignment is to build a K'nex car that meets the required project specifications and perform optimally in the Hill Climber competition as assigned by our client–Dr. Laura Moody. In this event, our vehicle must compete in multiple heats across a track at different levels of elevations.

1.2 Real World Applications

This project is relevant to the real world due to the aspect of having to design a product for a client that follows a list of specifications. The K'nex car project is much like a job an engineer would actually have. The project gives students experience with making PDR's and CDR's, and it gives students experience working in groups. By completing this project, students are also gaining experience designing and testing a product. This project gives us an opportunity to make preliminary designs before actually having the materials needed to build the car. This is similar to an actual engineering job in which you have to design your product before being able to build and test it. The K'nex car project has many real world applications, and it gives students experience with skills needed in an actual engineering job.

1.3 Rules for our Competition

Our client, Dr. Laura Moody, assigned us the Hill Climber event. The Hill Climber consists of multiple rounds in which the cars must travel up a hill at a specific inclination. The lane's dimensions are 0.3048 meters wide and 2.4384 meters long. The track's elevation starts at 15.24 cm and increases by 15.24 cm sequentially for six rounds of the competition. Teams have a time limit of 90 seconds to make it to the finish line, and each team's attempt must commence within 60 seconds of being called or they lose that attempt. To win the Hill

Climber event, our team's car must be the first to reach the top of the hill while following all the rules of the event. During the Hill Climber competition, the vehicle must stay in its own lane, and it cannot interfere with other vehicles.

1.4 Vehicle Specifications

The project specifications were also assigned by our client, Dr. Laura Moody. The final product must be constructed only from the components in our parts kit. The teams cannot use glue for construction. Teams may not disassemble or modify the mousetrap, DC motor, and the spring motor in our parts kit. All parts of the K'nex car must travel with the vehicle when climbing. All K'nex cars must start themselves; no other aids are allowed.

1.5 Timeline and Due Dates

Table 1: Timeline and Due Dates

Date	*What's due?*
March 21	K'nex Proposal
March 28	K'nex Car PDR and Presentation
April 4	K'nex written Test Plan
April 6	Competition Day - Engineering Expo
April 18	K'nex Car CDR and Presentation

2. Selected Design Analysis and Justification

2.1 Description and Justification for Design 2

Our group selected Design 2 to test and build for the Hill Climber Event. The concept is a triangular frame with the majority of its weight concentrated in the front of the vehicle. The larger wheels in the front not only create more torque but also allow the car to cover more surface area as it moves along the track.

Although design 1 was the lightest and fastest design, its low torque, proportionate low gear ratio, will make it difficult for the vehicle to climb hills with steeper inclines. Design 3 has the highest gear ratio, but its low speed and large mass would impede it from climbing a hill within the permitted time.

Finally, Design 2 has the highest merit score. We recommend this design for the Hill Climber event for its efficient balance between velocity and gear ratio. This design has two-wheel drive. The numbers from our gear ratio came from putting the axle of the front wheels directly through the electric motor. We did not have any gears in the car to receive a satisfactory velocity. Our estimated maximum speed came from our first tests before the event.

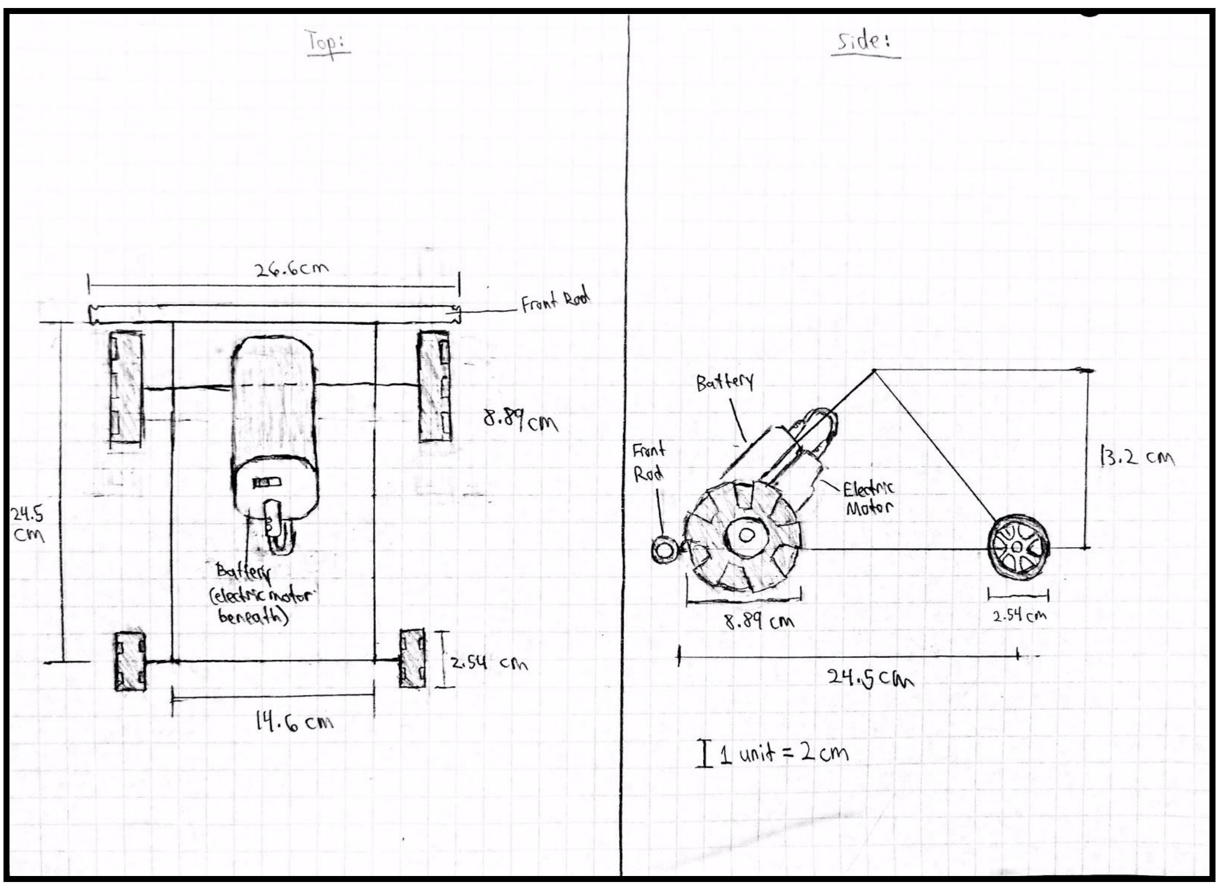

Figure 0: Sketch for final design

2.2 Feasibility Analysis for Design 2

Design met the required feasibility criteria before further consideration for construction.

Table 2: Feasibility Criteria Analysis

Criterion:	Design 2
Only composed of K'nex parts.	✔
Cannot be longer than 12"	✔
Cannot be higher than 18'	✔
Cannot be wider than the width of one lane	✔
Does not rely on rubber bands to produce motion	✔

2.3 Merit Analysis for Design 2

Design 2 received a overall score of 574. Design 2 distributes adequate performance across all three of the merit criteria. This design has the second lowest mass, the second highest velocity, and the second highest gear ratio.

However, design 2 has the highest merit score due to its high gear ratio, proficient velocity and middling weight. We recommend this design for the Hill Climber event for its efficient balance between velocity and gear ratio. While this design did not score the highest in either of these categories, we believe this car will demonstrate optimal performance across the criteria.

Table 4: Merit Analysis for Design 2

	Weight (%)	Feature Attribute	Merit Factor	Total Merit
Vehicle Mass	40	930 g	4.8	186
Velocity	20	0.30 m/s	5.8	116
Gear ratio	40	2.25	6.8	272
Total	100			**574**

3. Testing Plan

Our team will conduct the following tests to evaluate the performance of our vehicle prior to the competition:

3.1 Test 1

We examined how our car's performance with both the electric motor and the spring motor in order to know which motor will work the best during the actual testing day. With this test, we will know which motor performs the fastest for our event.

Results: After testing the velocity of both motors and their ability to propel our car up various inclines, we found that the electric motor performed the best. With the testing apparatus having no incline, the electric motor traveled at speeds of .31 m/s, .32 m/s, and .34 m/s, having an average velocity of .3233 m/s. With the spring motor at no inclinations, the three velocities recorded were .23 m/s, .25 m/s, and .26 m/s. The spring motor's average velocity based off of the test results is .2467 m/s. We used the electric motor during the actual Hill Climber event.

3.2 Test 2

In order to test the finished design, we will have the car drive over a track at varying inclinations. This will allow us to predict the car's performance during the actual rounds of the Hill Climber event.

Results: Once we started testing our car's ability to make it up all of the inclines used in the actual event, we found that our car was able to make it up every inclination in a reasonable amount of time. The result of the amount of time that our design went up each inclination is shown in Table 3.

Table 5: Results for Test 2

Inclination Height (inches)	*Time (seconds)*
6	9.12
12	10.47
18	12.08
24	13.38
30	14.78
36	15.77

3.3 Test 3

We conducted a test on our car by measuring its width and length. If the car is less than 30.48 cm long and 45.72 cm high, it will past the dimensions test. This test is being conducted so that our group will know if our car will fit on the hill climber track or not.

Results: Our car passed both the width, length, and height criteria for success. Our car is 14.6 cm wide, 24.5 cm in length, and 13.2 cm tall.

4. Design Modifications

When designing our K'nex car, we initially planned on using the yellow gears wrapped in rubber bands as the front tires. The 12.7 cm diameter gears worked well during the low incline tests, but once the testing apparatus was raised to heights of 30 inches or more, the car began to curve right and hit the wall each time. In an effort to fix this, we tried using the large black wheels instead of the yellow gears. We wrapped one rubber band around each tire to create more traction. The 8.89 cm tires worked very well at all inclines, and we finished second in the event due to this change. Another modification that we made was adding a K'nex piece that was wider than the car to the front bumper. We did this in order to prevent the car from running into the wall. If the bar hit the wall, the car would continue to climb up the hill. The modifications made to our original design helped our car to perform its best during the Hill Climber event. **See Figure 7 and 8 for the completed design.**

5. Building Instructions

5.1 Pictures of materials/parts

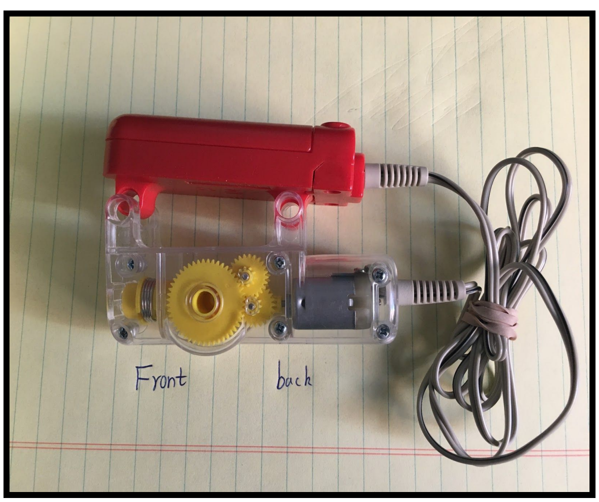

Figure 1: Motor

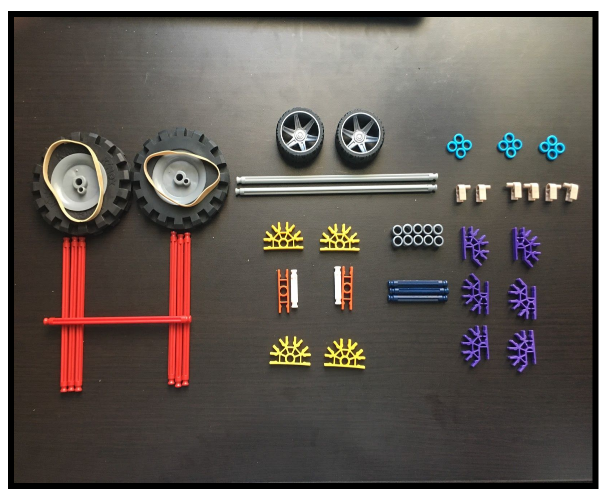

Figure 2: Other parts

5.2 Step by Step instructions for assembly

Stage 1: The first stage of the design is shown in **Figure 3 and Figure 4**, which is simply the front wheel being connected to the motor. The stage is composed of 10 grey rings, a grey rod two large black wheels with rubber bands, two beige connectors, and the battery motor. The figure is built by first sliding the grey rod into the gear hole of the motor, and then one will have to add the rings, the wheels with rubber bands on, and the beige connectors to the grey rod like what's shown in Figure 3.

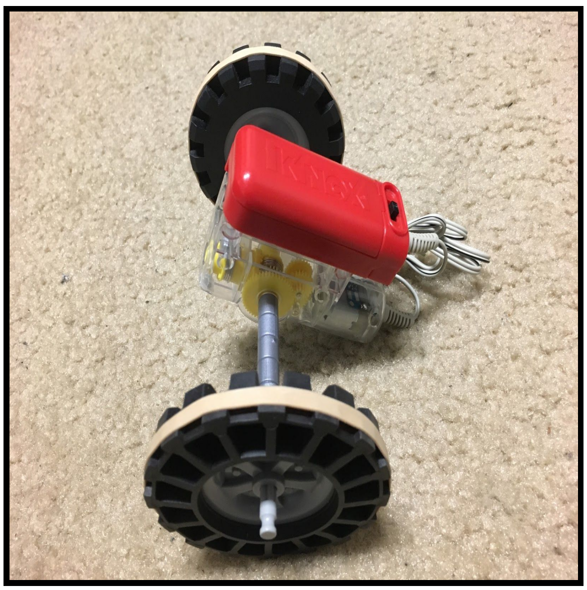

Figure 3 Stage 1

Figure 4 Stage 1- 2

Stage 2: The second stage of the design is the vehicle's body with rear wheels (See Figure 4). The body is composed of a grey rod, 4 yellow connectors, 5 red rods, two orange connectors, two purple connectors, two small wheels, a blue rod and two white rods. The figure is built by first connect the two yellow connectors to the grey rod, then one needs to connect each yellow connector with two red rods, one horizontally, and one with inclination (See Figure 4). Secondly, one needs to connect the ends of the inclined red rods with one yellow connector each; then, in between the yellow connectors, one has to add a blue rod.

Thirdly, one has to connect the two yellow connectors (with a blue rod in between) with one red rod each (downward sloping) (See Figure 4). Fourthly, one needs to connect each horizontal red rods with an orange connector with white rods attaching to it first (See Figure 4). Lastly, one needs to connect the downward sloping red rods with the white rods by adding a purple connector in between; the rear wheels with red rods in between will be added to the purple connectors.

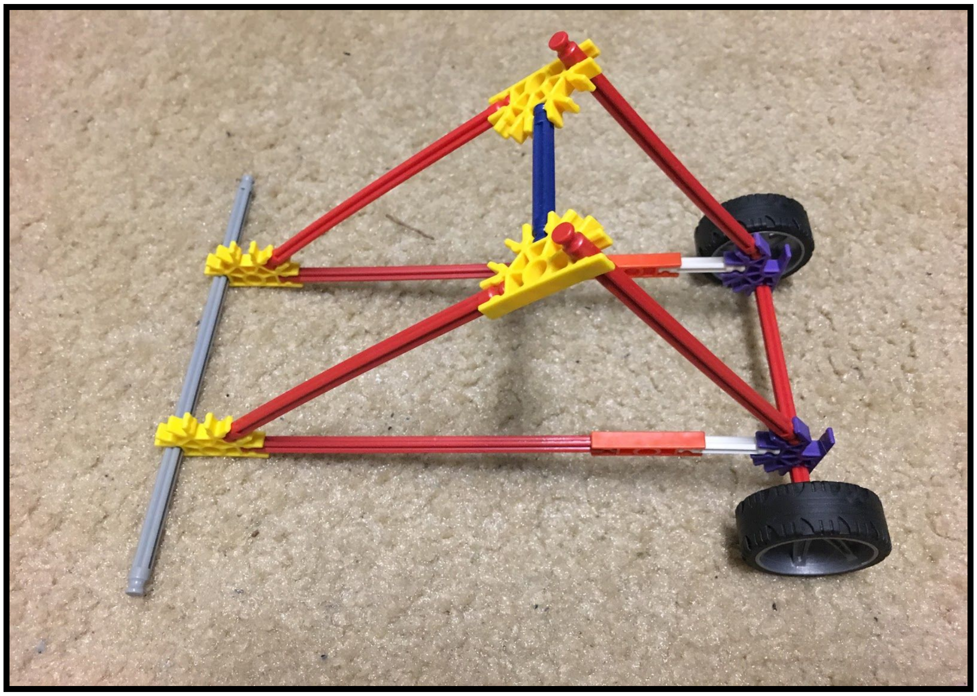

Figure 5: Stage 2

Stage 3: The third stage of the design is adding enhancement to the motor (Figure 5); the enhancement will allow the attachment of the body of the car (stage 2) to the motor itself. In order to complete this stage, one will need four purple connectors, eight blue rings, and two blue rods. The stage is completed by first adding the front and the rear holes of the motor with a blue rod. Then, one will have to add the blue rings to the two blue rods, two rings on each side. The last enhancement is completed by adding two purple connectors with each blue rod, one on each side. The purple connectors will allow one to attach the motor to the body of the vehicle (stage 2).

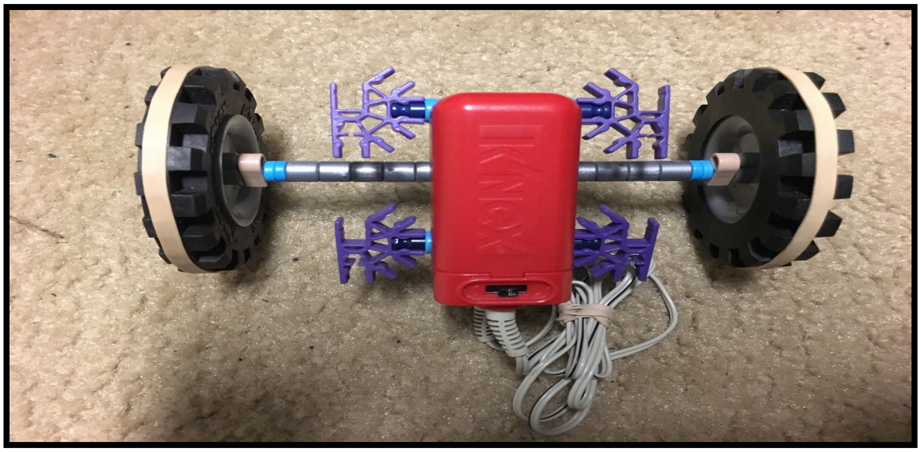

Figure 6: Stage 3

Stage 4: The final stage is simply connecting the motor with the front wheels to the body of the vehicle (**See Figure 6 and 7)**. One have to try to push for motor forward along as much as one can after connecting the purple connectors to the upward sloping red rod; this move will make sure that the front grey rod doesn't touch the ground when traveling.

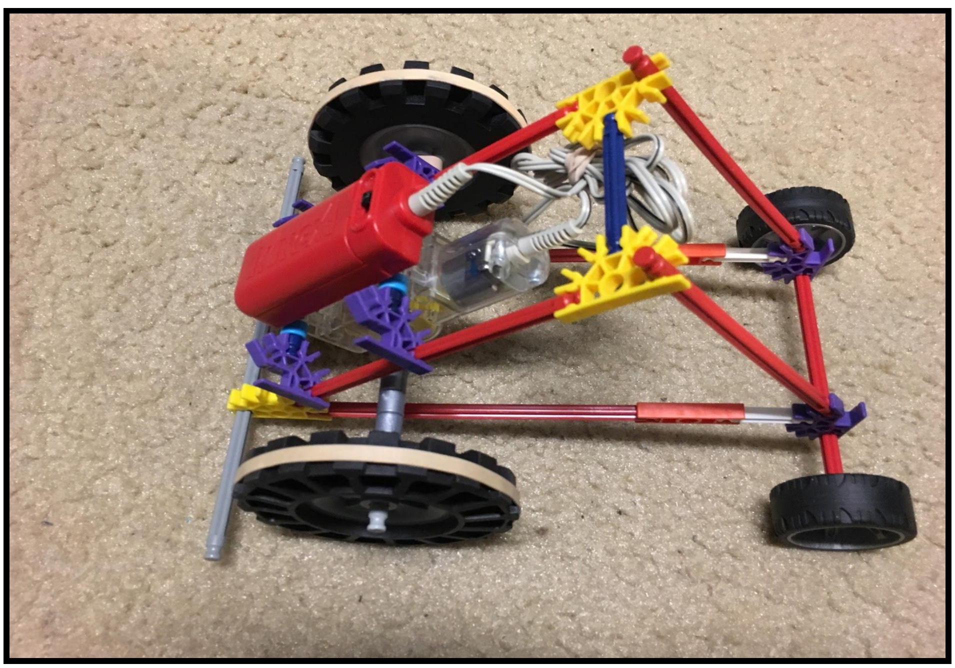

Figure 7: Stage 4 - 1

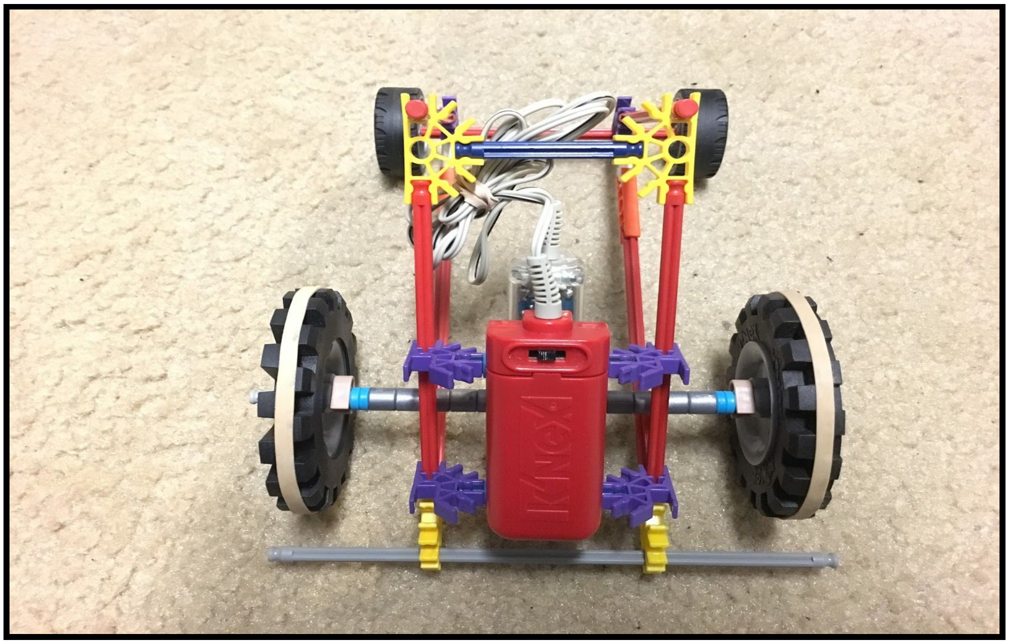

Figure 8: Stage 4 - 2

6. Financial Analysis

The cost of producing 1,000 K’nex car kits has two variations- assembled and sorted kits. Both kits contain the same parts; however, assembled kits are built prior to being shipped, and thus require more labor to produce. Our business oversees 10 employees that are paid an hourly wage of $15.00 each. To create a reference for labor cost calculations, we measured the amount of time required for two employees to assemble one kit following the instructions provided in the previous section, and then repeated the process to measure the required time to produce one sorted kit. One hour breaks for each eight hour work day for employees were included in the final calculation of labor costs. The total time required to produce each type of kit is calculated assuming that five teams of two employees are working simultaneously. A summary of information regarding labor costs is provided in Table 6.

Table 6: Labor Costs

	Assembled Kit	Sorted Kit
Time to produce one kit	13 minutes	8 minutes
Hours to produce 1000 kits	49	30
Wages to produce 1000 kits	$7,350	$4,500
Employee Benefits	$1342.11	$821.70
Total Labor Costs	$8,692.11	$5,321.70

The gross cost of the materials for 1000 kits of either type is $5,430. A bulk discount of 15% is applied to our order, reducing the materials cost to $5,158.50. Shipping and handling, which is calculated prior to any discounts, costs $271.50. A summary of the direct costs (materials, labor, shipping), indirect costs (utilities, maintenance, appliances), and the total budget for both Assembled kits and Sorted kits is provided in Table 7 below.

Table 6: Budget Summary

	Assembled Kit	Sorted Kit
Direct Costs	$14,122.10	$10,751.70
Indirect Costs	$17,652.60	$13,439.6
Total Budget	$31,774.70	$24,191.30

7. Competition results and Recommended Modifications

In conclusion, our K'nex car design was overall effective, and it met all of the feasibility and merit criteria. It produced a high torque, with an adequate velocity of .32 m/s, and an acceptable weight of 369 grams. The car placed 2nd in the Hill Climber competition; with some adjustments this design, such as making the car lower to the ground and making the car lighter, we feel it could perform better in the event. Our group recommends that future EGR 107 students start to construct their cars immediately in order to have plenty of time to work on their designs. Another recommendation is to put more emphasis on the velocity and the gear ratio.

8. Summary

The purpose of this project is to introduce fundamental engineering concepts to the students by giving them the opportunity to work with a client, just like in a professional situation. The objective of the project is to build a K'nex car that meets the required project specifications and performs the best at the Hill Climbing event assigned by our client, Dr. Moody. The car must follow all rules for its assigned event; it must also meet the feasibility criteria that are based on the project specification assigned by our client.

We proposed three separate preliminary designs, and, each has their strengths and weaknesses. We chose one of these designs to build out of the given materials to compete in the Hill Climber event.

All of the preliminary designs were adequately designed according to the feasibility criteria, but had different scores when evaluated through the merit criteria. We chose design 2 for its proficiencies in all the merit criteria. We conducted three different tests for our merit criteria before the final competition. During the performance test by using the testing apparatus, our design kept curing to the right as it traveled up the elevations that are greater than 30 inches. However, after switching the design's front wheels from the 12.7 cm gears to the 8.89 cm black wheels, the design successfully traveled up all inclines without any curvature. Our design also successfully passed all other tests. Our design came in second place after the Hill Climber Competition; during the final round, our design's speed was inferior compared our opponent.

Appendix

Feasibility Criteria

The feasibility criteria were selected based on the project specifications provided by our client, Dr. Moody. The designs must pass these feasibility criteria to be considered for production.

- The vehicle must only be composed of K'nex parts, and the parts can not be modified.
- Dimension constraints for the K'nex car:
  - Cannot be longer than 30.48 cm
  - Cannot be higher than 18”
  - Cannot be wider than the width of one lane
- The vehicle must be self-propelling. Motion can only be a result of the motor. The vehicle can not rely on rubber bands or external forces to produce its motion.

Merit Criterion : Mass

We chose mass as a merit criterion for our K'nex car because it impacts velocity. Ideally, the car's frame should be lighter so the motor will not be constrained. Additionally, mass proves a critical factor for this event since the vehicle will have to do more work $(W = F * D)$ against gravity with each round. For this reason, we made this merit criterion worth 40%. The minimum mass for the vehicle to receive a merit score is 500 g, and the maximum mass is 1300 g.

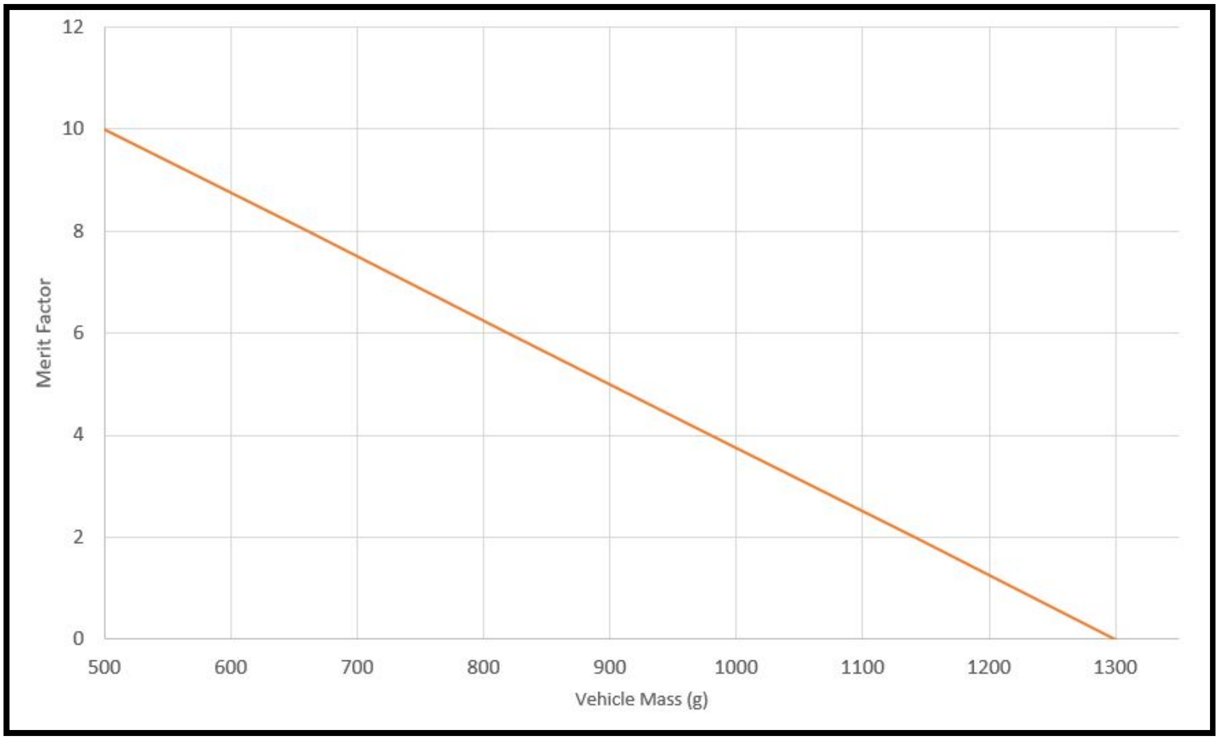

Figure 1: Merit Curve for Vehicle Mass

<u>Merit Criterion: Velocity</u>

We chose velocity as a merit criterion for this project since velocity would contribute to the result of the Hill Climber competition. Since each K'nex car will only have 90 seconds to climb the hill, velocity is a quality that will ensure the vehicle can travel the necessary distance within the maximum of 90 seconds. Furthermore, the team with the fastest car in the last round (hill with the largest incline) will be the winner of the Hill Climber. The weight of this merit criteria is 20% because it will ensure the K'nex car competes in the entirety of the event, and may even be the deciding factor in winning the competition.

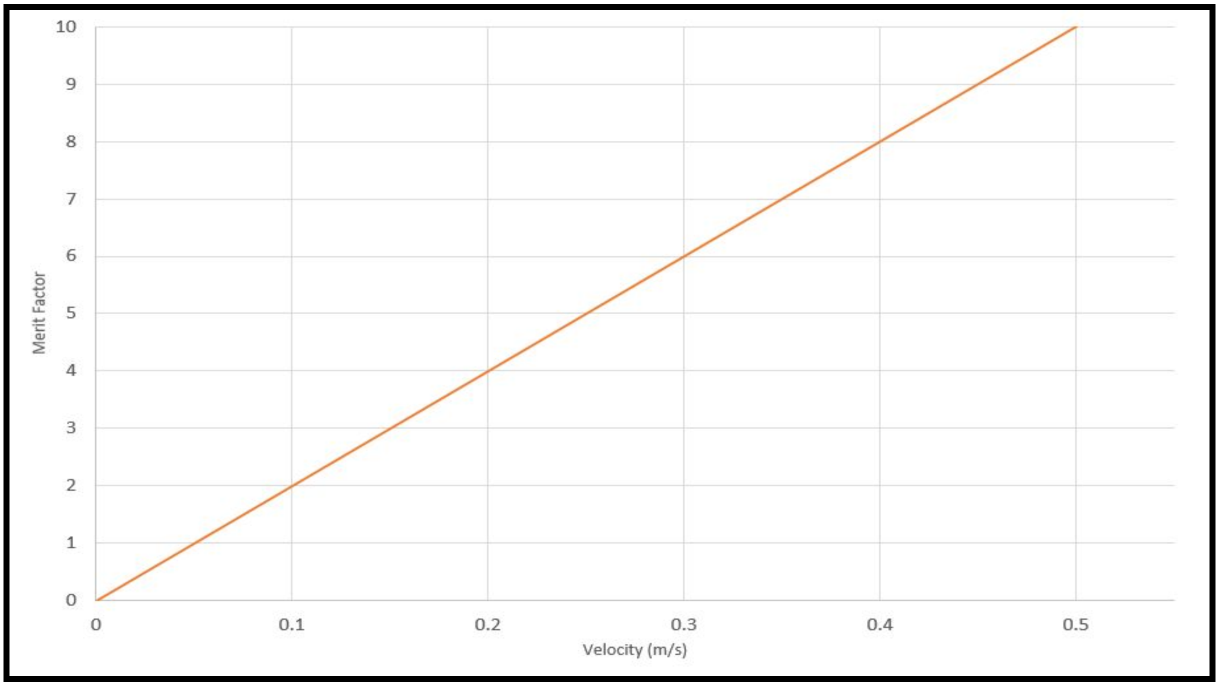

Figure 2: Merit Curve for Velocity

Merit Criterion: Gear Ratio

We chose gear ratio as a merit criterion for this project as gear ratio is directly proportional to the torque of the vehicle, which will determine the amount of gravitational force the car can counteract. This characteristic greatly depends upon the diameter of the gears embedded in the vehicle, and their locations. Greater gear ratio means larger torque, which will help our K'nex car to complete the later stages of the competition as the hill becomes steeper. The merit weight for this criteria is 40% not only for its value to the car's performance but also because it accounts for the car's overall design. The formula for gear ratio is show in **Equation 1;** in our case, R_1 is the radius of the gear attached to the motor, and R_2 is the radius of the gear attached to the first gear and each respective wheel. A higher gear ratio is indicative of higher torque, and thus of higher performance in the Hill Climber event. As such, a higher gear ratio will result in an increased merit factor.

$$\text{Gear Ratio} = R_1/R_2$$

Equation 1: Gear Ratio

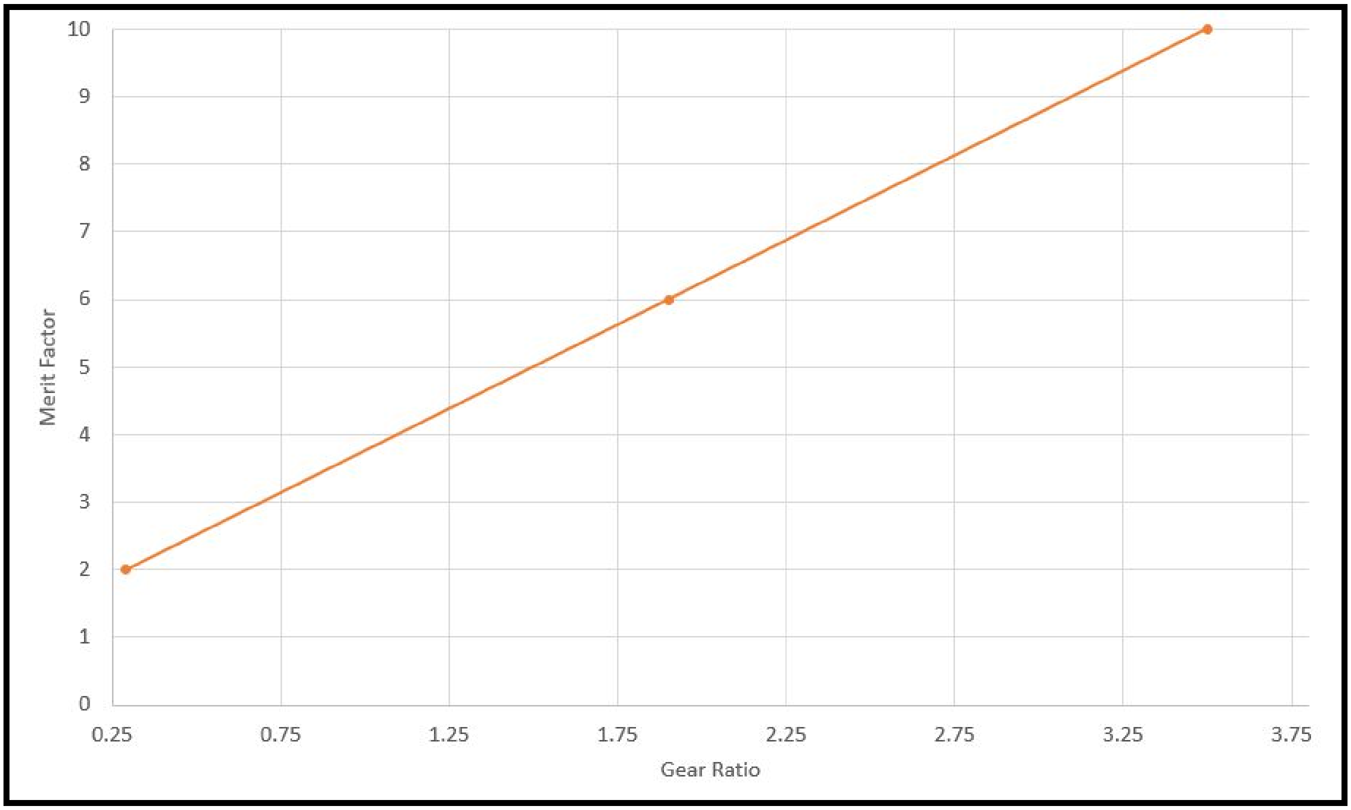

Figure 3: Merit Curve for Gear Ratio

Design Alternative 1

Design 1 will be a two-wheel drive K'nex car; the design will have a 5.715 cm diameter wheel in the front, and a 12.7 cm diameter wheel in the back. The motor will be placed approximately 7 cm behind the front wheel; a 8.89 cm diameter gear will be connected between the front wheel and the motor. The design will be 30 cm in length, 13 cm in width, and 8 cm in height. The estimated mass for design 1 is 900 g. The estimated gear ratio for design 1 is 0.29 (using gears with 1.27 and 4.45 cm radii) and the estimated speed for this design is 0.31 m/s. All of the estimated dimensions are based on the motor properties and other information provided by our instructor. The advantage of this design is the proximity between the motor and the front wheel, which represents even weight throughout the vehicle. In addition, design 1 have a decent estimate of the velocity, which will make design 1 succeed in meeting the time limit in each round of the hill climber competition. One disadvantage of design 1 is that it has a low gear ratio, which means it will have difficulty climbing the hills with large inclination.

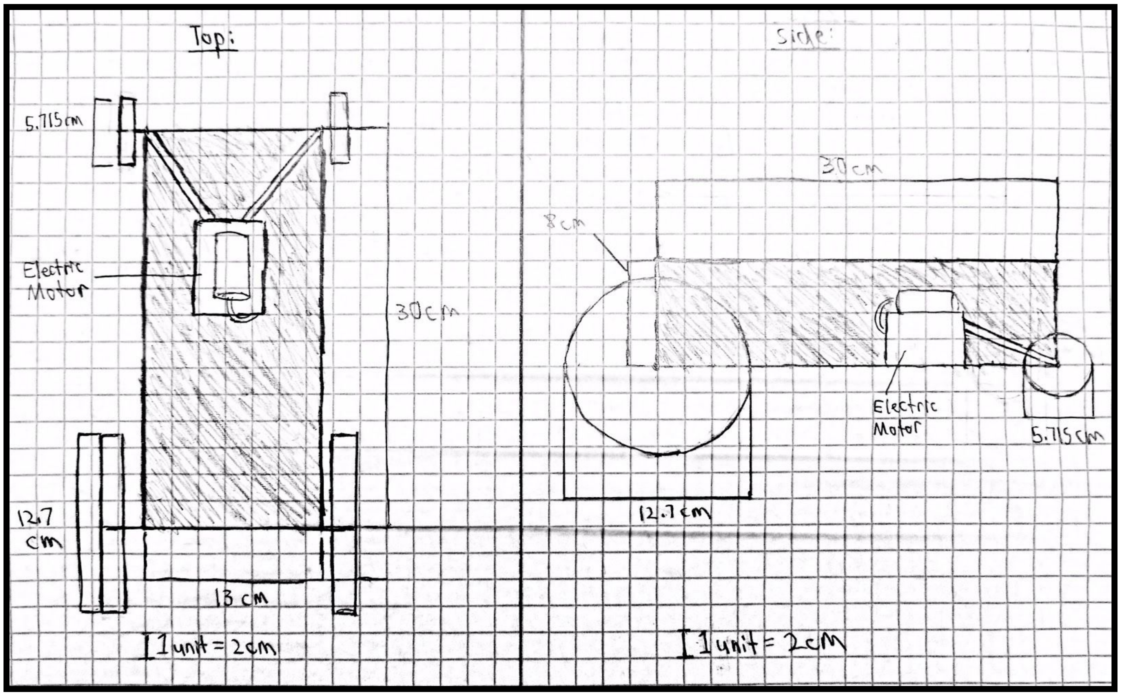

Figure 4: Design 1

Design Alternative 2

Design 2 will be a two-wheel drive K'nex car; the design will have two 12.7 cm diameter wheels in the front and two 4.13 cm diameter wheels in the back. The vehicle will be about 25 cm in length, 10 cm in width, and 18.7 cm in height. The motor will be placed approximately 2 cm behind the front wheels. The estimated mass of this design is 930 g. The estimated speed and gear ratio for design 2 is 0.30 m/s and 2.25 (using gears with 2.8575 and 1.27 cm radii), respectively. All of the estimated dimensions are based on the motor properties and other information provided by our instructor. The advantage of design 2 is that most of the vehicle weight is in the front, which is where the motor is placed; this is beneficial for the hill climber competition because less weight in the back represents more strength against the different inclinations of the hill.

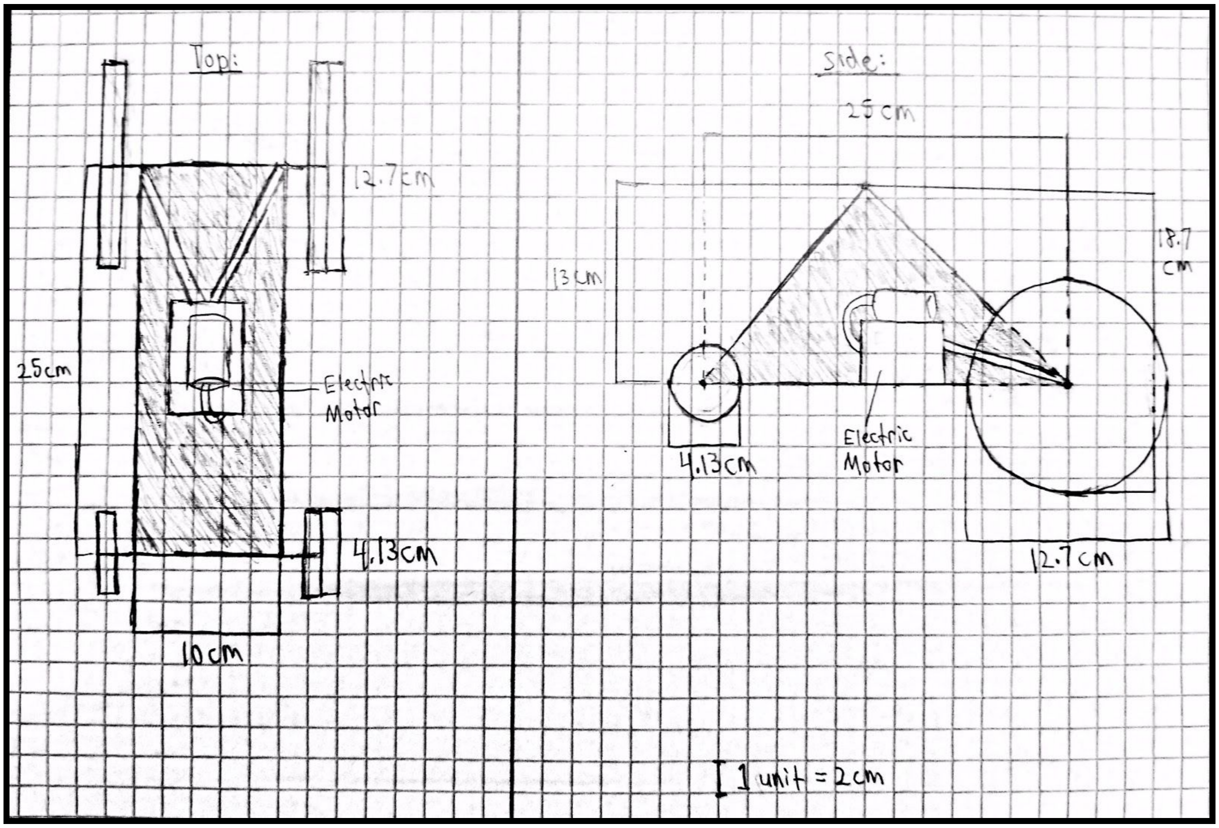

Figure 5: Design 2

Design Alternative 3

Design 3 is a four-wheel drive K'nex car. The design will have two 12.7 cm diameter wheels in the back and two 8.89 cm diameter wheels in the front. An engine will be attached to each of the car's axles, and the car will be approximately 27 cm in length, 14 cm wide, and 15 cm tall. The motors will be placed next to each other in the middle of the car to give the car an evenly distributed weight. The car has an estimated mass of 1200 grams. The estimated speed is about .2m/s, and the estimated gear ratio for design 3 is 3.5 (using gears with 4.445 and 1.27 cm radii). All of the estimated measurements are based on the information provided to us by the professor. The advantage of this design is its high gear ratio. This design is intended to have the highest possible torque of all three designs, and it has an evenly distributed weight due to the positioning of the motors. The bigger wheels in the back allow the vehicle to travel more distance with one rotation of the wheel vs. one rotation of a smaller wheel. One disadvantage of this design is that in correlation to its high gear ratio, it has the lowest estimated speed out of all three designs.

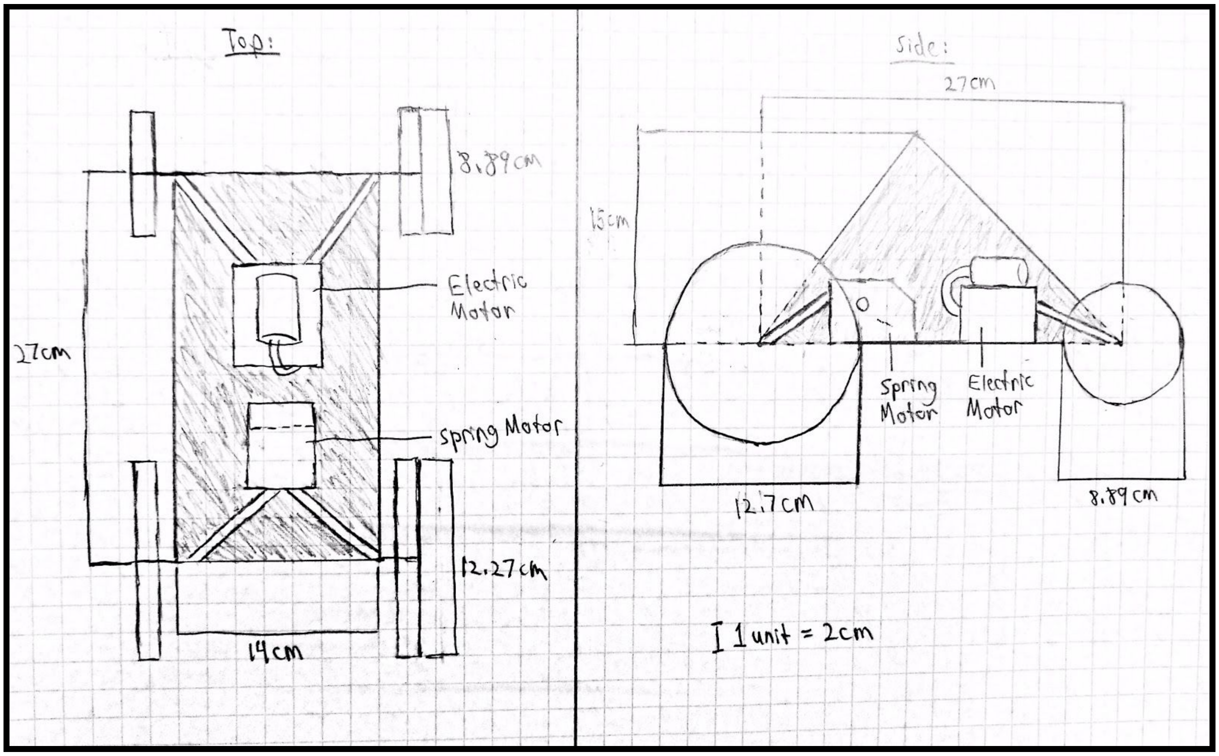

Figure 6: Design 3

Feasibility Analysis

All of the designs proposed meet the feasibility criteria for the K'nex car project, as they have all been designed with them in mind. They all meet the required dimensions, and can all be constructed using the given K'nex parts.

Table 2: Feasibility Criteria Analysis

Criterion:	Design 1	Design 2	Design 3
Only composed of K’nex parts.	✔	✔	✔
Cannot be longer than 12”	✔	✔	✔
Cannot be higher than 18’	✔	✔	✔
Cannot be wider than the width of one lane	✔	✔	✔
Does not rely on rubber bands to produce motion	✔	✔	✔

Merit Analysis for Design 1

Design 1 received a overall score of 514. Design 1 is the lightest among all other preliminary designs; also, design 1 has a decent speed, which means that it will succeed in meeting the time limit of each round of the competition. However, design 1 has a low gear ratio, which results in less torque to counteract the gravitational force when climbing the hill.

Table 3: Merit Analysis for Design 1

	Weight (%)	Feature Attribute	Merit Factor	Total Merit
Vehicle Mass	40	900 g	5	200
Velocity	20	0.31 m/s	6.2	124
Gear ratio	40	0.29	2.05	82
Total	100			**406**

Merit Analysis for Design 3

Design 3 received a total score of 532. This design has the highest gear ratio of all three designs, but it also has the lowest velocity. Design three is also the heaviest of all three designs. This car is intentionally designed to have high torque, referring to its high gear ratio; however, the mass is proportional to the increase in gear ratio.

Table 5: Merit Analysis for Design 3

	Weight (%)	Feature Attribute	Merit Factor	Total Merit
Vehicle Mass	40	1200 g	1.3	52
Velocity	20	0.20 m/s	4	80
Gear ratio	40	3.5	10	400
Total	100			**532**