University of Portland
Donald P. Shiley School of Engineering
MEMORANDUM

DATE: March 13, 2020

TO: Dr. Kenneth Lulay

FROM: Team A9: Patrick Carr, Jeremiah Eriksen, Ernesto Zurita Ruiz, Philip Warthen

SUBJECT: Gear Ratio Theory Testing Results (DID 6, KG 5)

As requested, the following are the results of an experiment to test gear ratio theory using the supplied LEGO Mindstorms motor and gears. Initial testing was conducted on 03/09/2020 and a follow up test occurred on 03/12/2020. See the attached test-plan for the overall procedure and data collection.

Table 1 shows the results from our follow up test which shows strong agreement with gear ratio theory. Figure 1 shows the finalized test setup which was found to minimize losses due to friction and various systematic error.

Table 1: Results from follow up trial with error corrected, conducted 03/12/2020

Mass Applied (g)	Power output - measured (Nmm/s)	Motor Angular Velocity ω_{in} (rad/s)	Drum Angular Velocity ω_{out} (rad/s)	Gear Ratio (ω_{out} / ω_{in})	Percent Error
Gear Ratio = 1.68 : 1 (driver : driven)					
50	136	13.38	24.97	1.68 : 1	0%
250	580	13.94	21.22	1.52 : 1	9%
500	944	15.22	17.27	1.15 : 1	32%
750	1018	15.57	12.41	0.80 : 1	53%
1000	900	15.02	8.23	0.55 : 1	67%
Gear Ratio = 1 : 1.68					
50	44	13.41	8.09	1 : 1.66	1%
250	196	13.40	7.18	1 : 1.87	10%
500	376	13.55	6.87	1 : 1.97	15%
750	418	13.62	5.10	1 : 2.67	37%
1000	479	13.72	4.38	1 : 3.13	46%

The data shows that gear ratio theory held true for all our trials conducted with a low applied mass. Above 500g, however, it was found that the experimental results deviated from theory by as much as 67%. This difference is due to the nature of the test setup used. We applied masses of up to 1000 g to a shaft made of plastic and secured with LEGO bricks. We observed extreme flex in the shaft and rolling drum when a mass greater than 500 g was applied. This flex induced heavy losses to the system which forced the motor to output more power than theoretically necessary. Thus, the results are satisfactory for proving gear ratio theory based on the data gathered for masses between 50 and 500 g.

The results from Table 1 were found following major adjustments made to our test setup following lessons learned in the first round of testing on 03/09/2020. Table 2 and figure 2 show the results from these tests and how they were performed.

The testing equipment in this initial test was not secured properly to the LEGO baseplate for testing. This resulted in major flex and many failures of the test setup whilst attempting to gather data. Thus, the data collected contained more error due to the losses and error mentioned above. From this test, the procedure and testing setup was redesigned to reduce error.

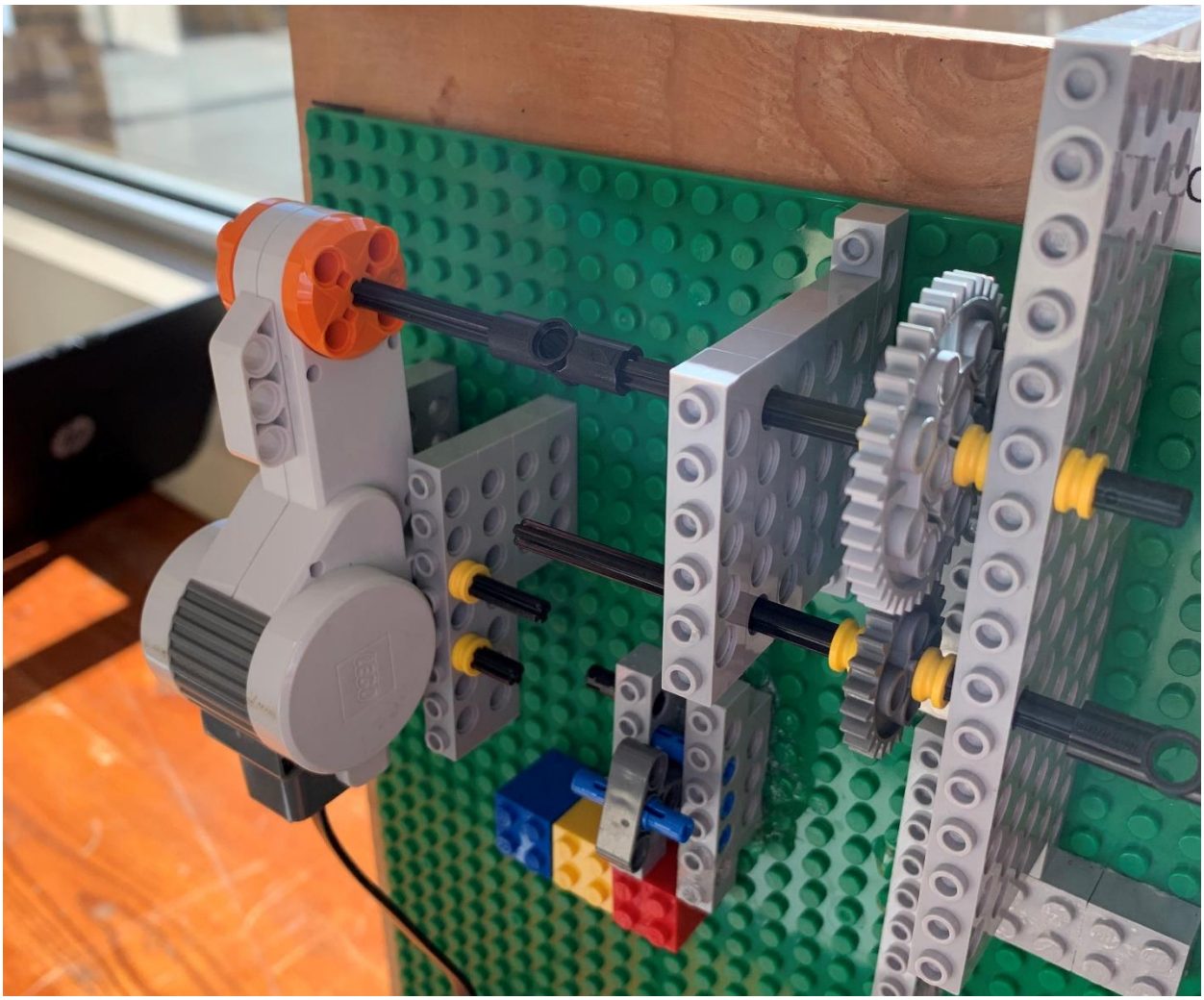

Figure 1: Revised Test Setup and Gear Transmission

Table 2: Results from first trial, conducted 03/09/2020

Mass Applied (g)	Power output - measured (Nmm/s)	Torque Input from Motor T_{in} (Nmm)	Output Torque T_{out} (Nmm)	Gear Ratio (T_{in} / T_{out})	Percent Error
Gear Ratio = 1.14 : 1 (driver : driven)					
50	-	-	-	-	-
250	324	22.0	27.3	0.80	29 %
500	540	34.9	54.7	0.64	44 %
750	715	52.2	82.0	0.64	44 %
1000	611	41.2	109.4	0.38	67 %
Gear Ratio = 1.68 : 1					
50	96	18.5	5.50	3.38	101 %
250	474	30.0	27.3	1.10	35 %
500	870	72.7	54.7	1.33	21 %
750	956	86.0	82.0	1.05	38 %
1000	-	-	-	-	-
Gear Ratio = 2.00 : 1					
50	100	18.5	5.50	3.37	69 %
250	490	31.1	27.3	1.14	43 %
500	876	73.6	54.7	1.34	33 %
750	-	-	-	-	-
1000	-	-	-	-	-
Gear Ratio = 2.47 : 1					
50	123	18.4	5.50	3.36	36 %
250	380	24.5	27.3	0.89	64 %
500	-	-	-	-	-
750	-	-	-	-	-
1000	-	-	-	-	-

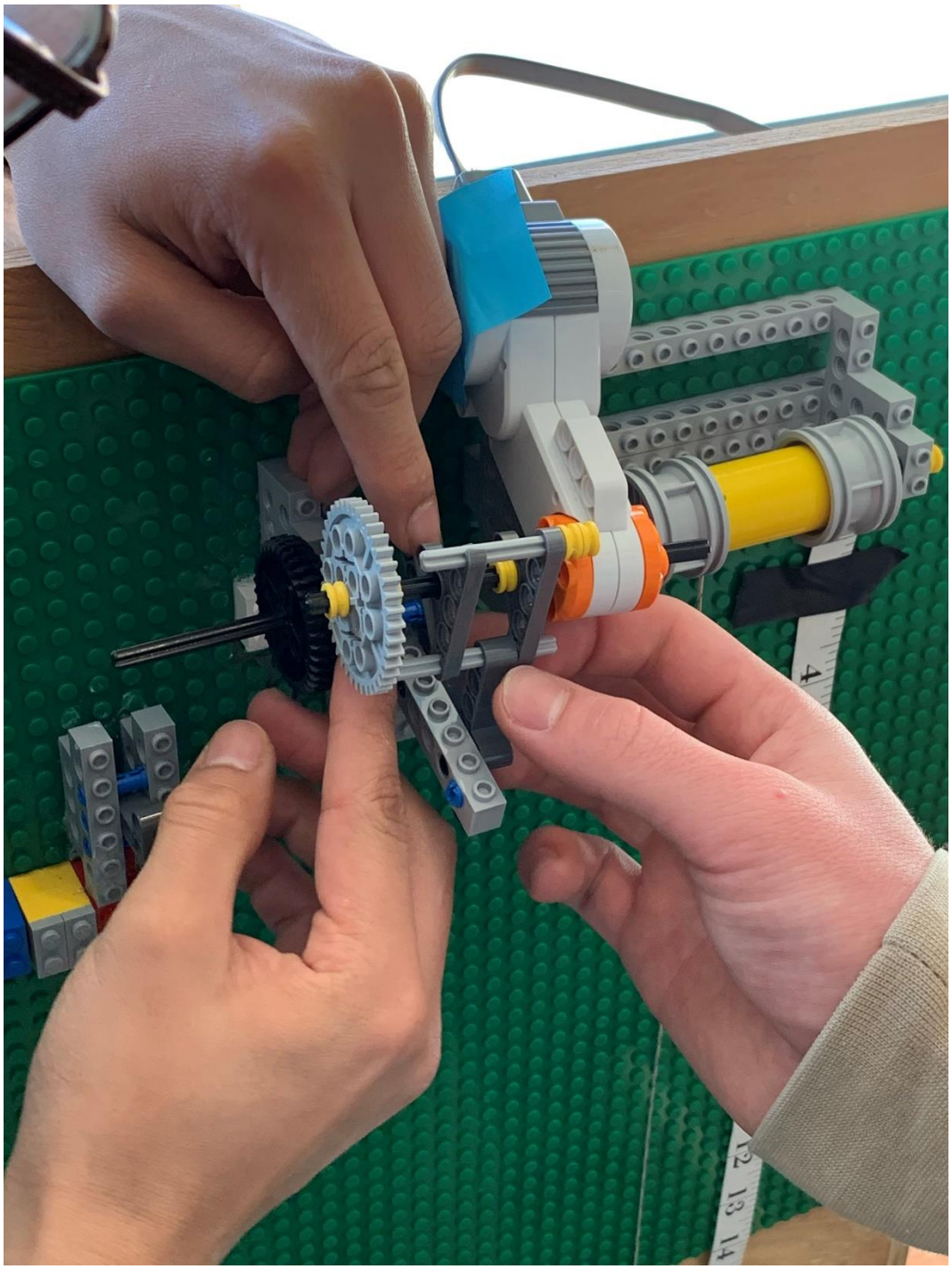

Figure 2: Test setup used for initial test.

Observations:

- Drive gear was attached to an articulating arm which was secured by hand to the driven shaft gear.
- Motor was attached to drive shaft by hand
- Considerable flexing was observed in the drive shaft & articulating arm

TEST PLAN FOR GEAR RATIO THEORY TESTING
ME-328 Team A9
March 9, 2020

The purpose of this test is to prove the validity of gear ratio theory on the LEGO motor setup provided for use in phase 1 of the African Plow Project. The theoretical equations must be proven before we can be sure we can rely on them for picking the best gear ratio for use in the device. The theory will be tested using various gear ratios on the motor previously characterized with a performance curve. The known output of the motor will be compared with the output torque of the gear ratio to see if the expect results are indeed found to be true. Once these tests are completed, a gear ratio will then be selected for the device.

Procedure:

- Select 4 gear ratios for testing.
  - Selected ratios: 40t/36t **(1.14)**, 40t/24t (**1.68)**, 40t/16t (**2.00)**, 40t/12t **(2.47)**
  - Set aside the necessary gears for each trial.
- Construct the necessary supports for the gears on the test bench.
- Load the output shaft with weights ranging from 0 to 1000g in increments of 250g.
  - For each weight load, record the time it takes for the weight to raise a set amount of distance.
- Repeat procedure for each gear ratio.

Team Approval:

Table 1 – Data sheet for gear ratio theory testing.

	Applied Mass Load – Time to Raise (s)				
Teeth Ratio (Diameter Gear Ratio.)	50 g	250 g	500 g	750 g	1000 g
40t/36t (1.14)	-	1.25	1.50	2.05	2.65
40t/24t (1.68)	1.32	1.33	1.45	1.98	-
40t/16t (2.00)	1.40	1.43	1.60	-	-
40t/12t (2.47)	1.64	2.13	-	-	-

After testing notes:

- Testing setup did not allow for testing of some heavy masses due to lack of support structure available. Considerable error was generated when attempting to align the gears by hand, with no proper support in the LEGO structure.
- 50g Test was not performed on the 1.14 gear ratio setup.

REVISED TEST PLAN FOR GEAR RATIO THEORY TESTING
ME-328 Team A9
March 12, 2020

This is a revision to the test plan used on March 9, 2020

Procedure:

- Select 1 gear ratio for testing.
  - Selected ratio: 40t/24t (**1.68 : 1 & 1: 1.68)**
- Construct the necessary supports for the gears on the test bench.
- Load the output shaft with weights of 50g, 250g, 500g, 750g, and 1000g.
  - For each weight load, record the time it takes for the weight to raise a set amount of distance.
- Swap the gears on the gear ratio and repeat the tests.

Table 2 – Data sheet for revised gear ratio testing (3/12/2020)

	Applied Mass Load – Time to Raise (s)				
Teeth Ratio (Diameter Gear Ratio.)	50 g	250 g	500 g	750 g	1000 g
40t/24t (1.68 : 1)	1.04	1.10	1.20	1.33	1.66
24t/40t (1 : 1.68)	0.99	1.11	1.16	1.34	1.56