Thinking Like Murdoch

A Research / Design / Build Project for Senior Technological Design

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- Chair, PEO Education Committee (EDU), 2010 to 2012
- Member, OSSTF District 12 Professional Development Committee, 2009-2012
- Chair, PEO Engineering Education Conferences
    - 2008 – "What Students Want to Learn"
    - 2009 – "Outreach Through Partnerships"
- ***Math in the Woodshop*** Aspiring Engineers project -- took 4 grade 9 students to 2014 PEO EDU Conference
- Speaker at Ontario Association for Mathematics Education 2016 Conference
    - ***Algebra is a Balance: Extensions to the Law of the Lever***

With the Enthusiastic Assistance of Aspiring Engineers at SATEC

Scarborough Academy for Technological, Environmental and Computer Education

- Melanie Tham (grade 11)
- Hassan Karim (grade 11)
- Mymoon Bhuiyan (grade 11)
- Isha Cheema (grade 11)

John Murdoch's "*Wooden Horse on Wheels*"

Some initial research -- find these quotes on-line:

William Murdoch's father, "the honest and scientific proprietor of Bella-miln, made a wooden horse on wheels, on which, by the assistance of propelling poles, he used to visit Cumnock."

"Mr Fergusson, the self taught philosopher, told of a new invented machine which went without horses: a man who sat on it turned a handle, which worked a spring that drove it forward."

Do some more research that might inform how you could replicate Murdoch's mid 18^{th} century ***Wooden Horse on Wheels***, believed to be the western world's earliest human-powered vehicle.

Might It Have Looked Like This?

- The hardwood model, mostly:
  - White Ash
  - Sugar Maple
  - Black Cherry

A Teacher's Perspective and Inspiration

The golden age of Scottish culture was achieved largely by the Lowland middle class with the approval and patronage (but not the initiative) of the landed [wealthy] classes, against a complex background of historical change.

T.C. Smout, renowned historian

Relevance and significance today for aspiring engineers…

A Little Background…

- Make no mistake – the "deck was clearly stacked against" ordinary folk in early 18th century lowland Scotland.
- Scotland was a poor country during that pre-industrial-revolution period.
- But ordinary Scottish folk "rose to the challenge".

- What exactly was the challenge back then – three centuries ago?
- A non-trivial question for sure, but suffice it to say that the challenge was to “improve” – improve agriculture, improve social conditions, improve education, improve the local, regional and national economy.
- So the late eighteenth / early nineteenth century in Scotland came to be known as the “*Age of Improvement*”.

And why is this important today?

- The pace of change seemed to be "*out of control*" during the agricultural revolution in the mid to late 18th century.
- Ordinary Scots responded and had a profoundly positive impact, not only on life in Scotland, but in many other parts of the world.
- For example, see *http://www.scottishdiasporatapestry.org/ca12-from-croft-to-clearing*

And today change is, again, seemingly “*out of control*”

- At times, in ways that we can’t even begin to imagine.
- A surprise headline at every turn has us asking “what next”?
- The takeaway from this:
  - *If the ordinary lower middle class eighteenth century Scots could take a leading role in the age of improvement…so can our youth in this twenty-first century era of radical change.*

How Did Those Lower Class Scots Achieve So Much?

- First let's be sure that we appreciate the positive impact of very ordinary people during that pre-industrial era.
- We'll use John Murdoch and his technology breakthrough -- his "*Wooden Horse on Wheels*" -- as our case study and design / build project.
- Today's students can learn to "***Think Like Murdoch***" as they grow their Lifelong Learning and Thinking skills.

Mr. McCowan's Classroom Mission Statement

Using the Ontario Curriculum, my job is to guide you to become a better thinker, a better learner, and a better problem-solver. Together, our job here today – and every day -- is to get you just a little bit closer to your own career goal.

D. B. McCowan, P.Eng., OCT

Evolution of Engineering Thinking
"Innovation"

- The great inventions of the industrial revolution in the late eighteenth century had their inspiration in the minds of young innovators who had grown up during the early years of the agricultural revolution.
- John Murdoch's "*wooden horse on wheels*" is believed to be the first human-powered vehicle in the western world.

The Situation – A Millwright Ponders Improvement

- John Murdoch was a millwright at Bello Mill, Ayrshire.
- As a bonafide mechanical engineer of the mid-eighteenth century, he built devices for use in the early decades of the agricultural revolution.
- Now, in 1754, Lord Dumfries' estate manager contacted Murdoch to get him to work on designing, building and installing some custom hardware at the new Dumfries House mansion, 4 miles from Bello Mill.
- John had a young family and wanted to be with them every night during the periods when he worked at Dumfries House.

- How could he get from Bello Mill to Dumfries House and back again every day in the least amount of time?
- He was not a full-time farmer, so did not own a horse.
- While John Murdoch certainly did not have CAD software to help him with his system design, we can be pretty sure that his project thinking and planning involved:
  - Setting a goal
  - Breaking down his goal into a set of targets at which to aim

Design Brief: Murdoch's Goal

A Concise Interpretation of the Situation

To modify a familiar shop helper tool – a saw horse … to convert it into a moving shop helper tool… a helper tool that would enable a tradesman to travel to a workplace, with his tools, more quickly and conveniently.

Requirements -- Murdoch's Thinking

Analysis & Synthesis of a Solution Framework

Fundamental Concept of Tech	Requirement – The "Wish List" Target to Aim For… The Modified Helper Tool Must…
Function	Move a tradesman a distance of 4 miles just as quickly as a horse could take him.
Ergonomics	Be light enough for a tradesman to move manually. The user must be fairly comfortable when using the product – the position the user is in must be "familiar" to the user.
Materials	Be made of wood and limited metal (keep it relatively light).
Control	Since the road was not straight, must be able to easily navigate curves and turn corners.
Structure	Members and joints / connections between members must be strong enough to take the repetitive shaking when travelling along the stony road.
System	The tradesman needs to take his tools with him.
Fabrication	Must be able to build the product using hand-tools, wood screws, nails and perhaps nuts / bolts.
Aesthetics	The product does not need to be pretty, but should at least exhibit "pride of craft". The product must look as though the builder was proud of his or her work.
Safety	The device must not suddenly / unexpectedly collapse such that the tradesman's fingers or toes can be severed.

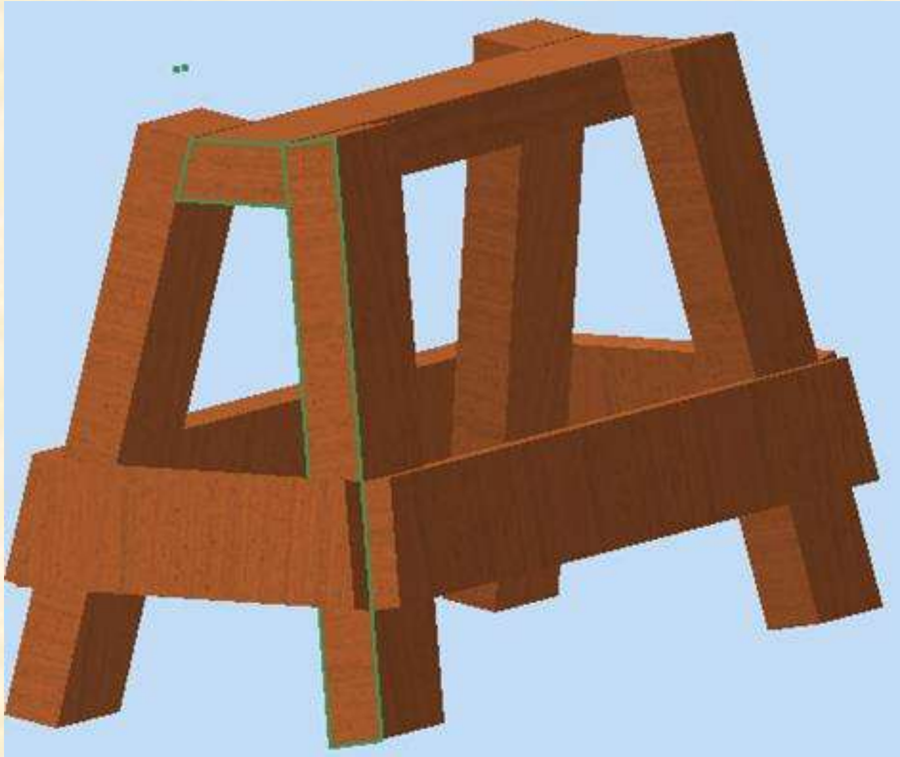
What Did Murdoch “Already Know”?

- As a skilled tradesman – a miller, millwright, joiner and perhaps even a British army gunner according to one source – he was quite familiar with carts (both 2-wheeled and 4-wheeled) and how they turned when being pulled by a horse.
- ***What other knowledge did Murdoch bring into this problem-solving / opportunity-seeking situation?***

A Bit of Knowledge His "Recall" Core Thinking Skill	**Adapting the Bit of Knowledge to the New Situation**
A ***lever*** allows one to move a heavy load with a reduced effort – a lever can magnify a force.	A lever can be used to ***magnify a distance*** – moving the lever a short distance will move the load a greater distance.
Grease can be used to ***reduce friction*** between parts sliding against one another.	Other techniques to reduce friction between parts must be possible.
That a ***wheel rotating on a greased hub*** will keep turning after the force that started it moving is removed.	***Reducing friction*** between parts that slide against each other is key.
A wheel and axle is really a ***special type of lever***.	***Distance Magnification*** is possible
His saw horse had four legs He also has a "shaving" horse which he sits on when "shaving" spokes for wheels	A horse has four legs… you sit on the horse… the horse ***moves you from point A to point B***…

Murdoch's Sawhorse "Helper Tool"

A Preliminary 3D CAD Project



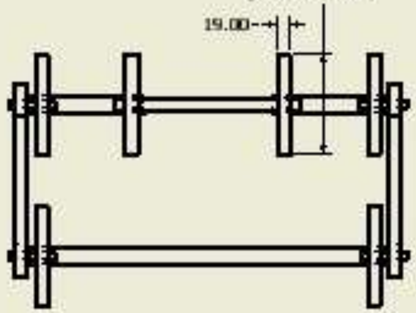
Now then, let's adapt the sawhorse to the desired purpose… ie, lets "***innovate***"…

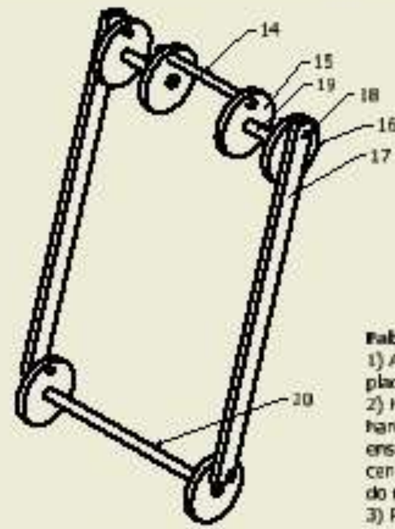
To Address the "Requirements" … Five Sub-Systems

- Structural Frame
- Steering
- Driving
- Rear Wheels
- Tool Storage

Interfaces between sub-systems need to be carefully considered.

NOTE: The top view and front view are NOT in the plane of the coordinate axis system. The right side. Only the right side view is in a coordinate system plane (XY in the model.)





Parts List				
#	Part Name	Qty	Cut Size mm	Fabr Note
14	Drive Handle	1	276 x 19.0 dia	1
15	Handle Drive Plate	2	150 dia x 19.0	2
16	Connecting Rod Drive Plate	4	150 dia x 19.0	
17	Connecting Rod	2	835.1 x 50.0 x 19	6
18	Drive Plate Pin	4	72.0 x 11.8 dia	3
19	Drive Plate Shaft	2	170.5 x 24 dia	4
20	Front Axle	1	526.2 x 24 dia	5

Fabrication Notes:

1) Add cotter pin at each end to prevent drive handle from s iding out of place.

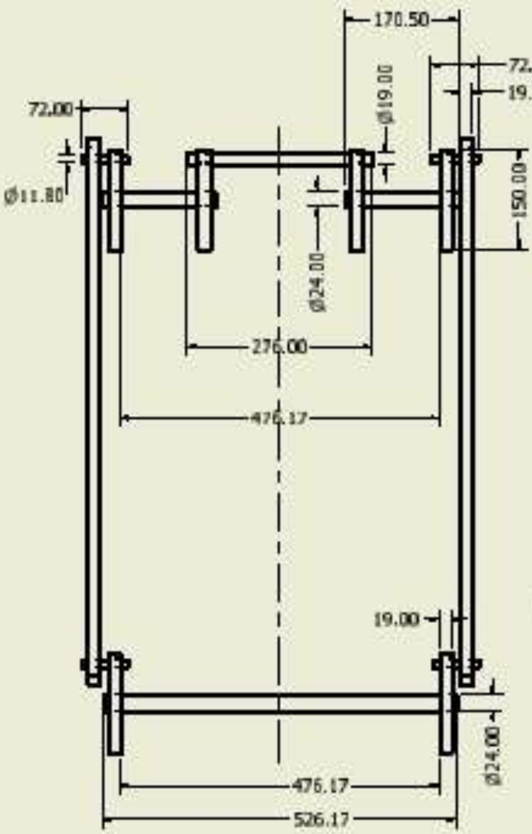
2) Hole in drive plate for drive handle must be large enough for drive handle to freely rotate with minimal friction. Use very fine sandpaper to ensure smooth sliding surfaces. Reduce radius from centre of hole to centre of drive p ate to 55.0 mm because the hand e dia was increased do not want the handle to break through the hole.

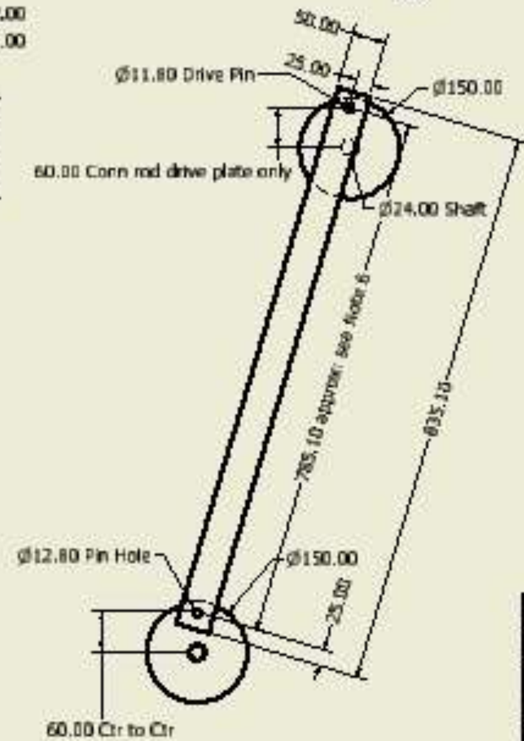
3) Rigidly fix one end of drive pin to the connecting rod. P ace a smooth washer between drive plate and connecting rod to minimize friction. Drive pin must rotate freely within drive plate hole. Add a cotter pin on other side of drive plate to prevent pin and connecting rod from sliding out of position.

4) Consult with Steering sub-system team. Slide drive plate shaft through the hole in the pair of steering frame braces (part #9). The shaft must rotate freely with minimal friction. Both ends of drive plate shaft must be rigidly connected to the drive plate. Do not attempt a press fit because of the potential for splitting. There must be no interference with connecting rod.

5) Consult with Wheels sub-system team. Slide front axle through the hole in one front leg (part #4). Rigidly attach front wheel to mid point of axle. Slide axle through hole in other front leg. The axle must rotate free y with minimal friction. Both ends of front axle must be rigidly connected to the drive plate. Do not attempt a press fit because of the potential for splitting (main concern is softwood). There must be no interference with connecting rod.

6) Do not drill holes in connecting rods until you meet with the Steering sub system team measure the required hole separation very carefully.





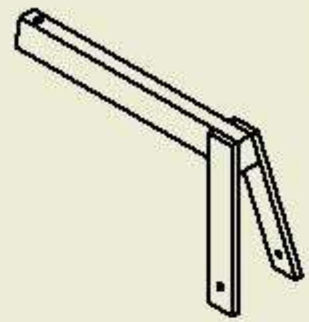
Version History		
V#	Description	Done By / Date
1	Corresponds to DBM2_Wheels_Master 1_V4_Dec14_16.ipt	DB McCowan Dec. 15/16

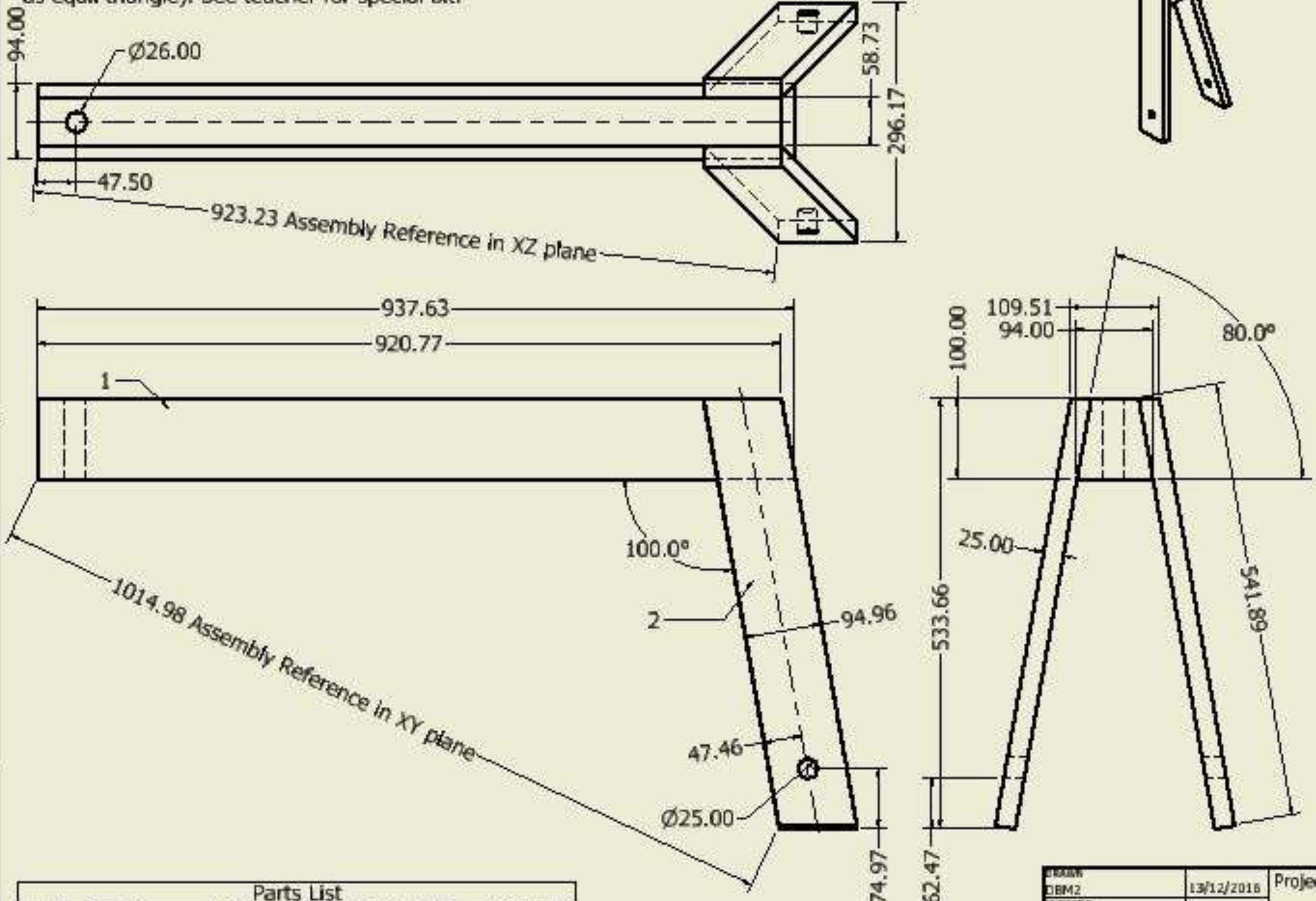
DRAWN DBMc	15/12/2016	Project: Murdoch's Wooden Horse on Whee s	
CHECKED		TITLE Driving Sub-Assembly	
QA			
MFG		Material: Team1 Softwood; Team2 Hardwood	
APPROVED			
Units: mm		SIZE C	DWG NO DBM2_WoodenHorseWheels_Dr REV
		SCALE	Do Not Scale SHEET 1 OF 1

Fabrication Notes -- Symmetry is Key (Note the 2 Centrelines)

1) May splice four 10.0 cm pieces on top of each other to obtain required vertical thickness. Both 80 deg chamfers must be accurate and smooth where legs attach.
INTERFACE 1: Do not drill hole for steering column until meet with Steering SS team.
2) Clamp legs strategically to Crossbar to prevent slippage while drilling for rods. To make use of the XY and XZ plane ref. dimensions, use long T-square and plumb bob.
INTERFACE 2: Do not drill holes for rear axle until meet with Driving SS team.
3) Drill 1/4" horizontal continuous holes through the 3 parts for threaded rods (space as equil triangle). See teacher for special bit.

Version History		
V#	Description	Done By / Date
1	Corresponds to DBM...MasterV3 Dec13/16	DBMc Dec13/16





Parts List				
#	Part Name	Qty	Cut Size (mm)	See Fab Note
1	CrossBar	1	950 x100 x 100	1
2	Leg-Rear	2	550 x 30 x 100	2
3	1/4-20 threaded rod	3	App 160	3

DRAWN DBM2	13/12/2016	Project: Murdoch's Wooden Horse on Wheels
CHECKED		TITLE Structural Frame Sub-Assembly
QA		Material: Team1 Softwood; Team2 Hardwood
MFG		
APPROVED		SIZE C — DWG NO DBM2_WoodenHorseWheels_St — REV
Units: mm		SCALE Do Not Scale — SHEET 1 OF 1

Does it Work? How'd We Do?

Stills from the video are on the next 4 slides:

1. No load
2. Low load
3. A pretty good load
4. Maybe our initial idea was a better strategy…

Viewer Discretion Advised!

https://www.youtube.com/watch?v=EaeWSi7pTB4

No Load

Low Load

Full Load

One Impression of the "Propelling Poles" ie No Drive Handle

Construction… & Some Lessons Learned

Good alignment of the pair of upper drive plate axles was crucial

Lock-nut pairs -- and careful tightening -- were used on both ends of threaded rods to avoid twisting of the 4 diagonal braces

The radial dimension from drive axle centre to connecting rod pin centre must be identical for both ends of connecting rod – a small pilot hole provided accurate positioning for the pair of drive plates.

- Double lock-nuts on both ends of threaded rod (tighten strategically to avoid twisting of diagonal braces)
- Design-time symmetry is a great thing -- but the steering column centering was not bang-on
- Spacer required above crossbar because of some assembly-time slippage of lower crossbar support
- **A Pleasant Surprise:** Consider the pair of connecting rods – the distance between their pair of drive pin holes
- Now consider all of the things that could have gone wrong
- The distance between the pair of drive pin holes – left connecting rod vs right connecting rod:
  - The difference was less than … _________ -- take a guess!

Pilot hole was drilled through the pair of inside drive plates
Then bored the blind hole for the Drive Handle

Drive Handle should have been a larger diameter, with a shoulder at each end to reduce “wobble”

For Next Time

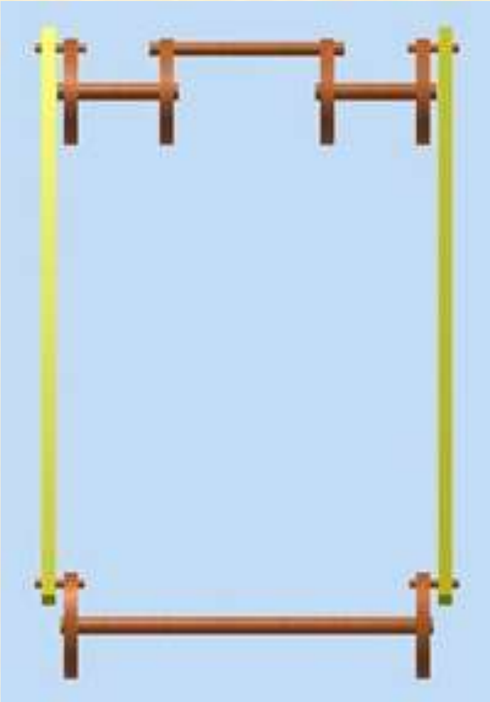
- The left side drive on front axle should have been 90° out of phase relative to the right side drive on front axle (a relatively easy fix)
- This would help maintain rolling inertia
- Completion (and some re-design) of the tool storage sub-system will strengthen the back end
- Tool storage will serve as foot-rest / running board

The Softwood Model: Clamping to accommodate the 80^{o} angles provided some challenges.

Anonymous Student Survey

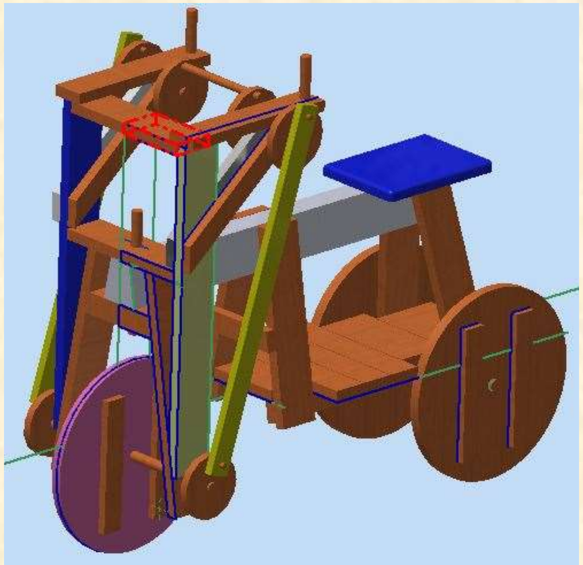
On a scale of 1 to 10 with 10 being "really awesome", how would you rate the "*Wooden Horse on Wheels Design / Build*" STEM Project?	Average Rating (21 Students) / 10
The Wooden Horse was a good learning experience in terms of Problem-Solving using the design process and 3D CAD software	8.5
The Wooden Horse was a good learning experience in terms of improving individual Essential Skills and Work Habits	8.3
The Wooden Horse was a good learning experience in terms of team collaboration	9.0
The Wooden Horse was a good learning experience in terms of development and application of shop skills	9.1

Next Year…



- Scale it down by a factor of 4
- Minimum wood material thickness / diameter of 0.25”
- We won’t include tool storage (to minimize weight)
- Remove the upper drive plates and drive handle

- Integrate stepper motors into the torso of a simulated mini-driver who will operate independent connecting rods



… Mechatronics

- We will decide how long it takes a drive plate wheel to complete one revolution
- With the known time, we'll program an Arduino board to rotate a step / pancake motor to run for that period of time.
- Briefly stop (so the miniature driver can go back to his original position) and then restart the simulated human body procedure
- And…

ARDUINO

The 2016 Project -- Update

On a scale of 1 to 10 with 10 being *awesome*, how would you rate the "***Thinking Like Telford Menai Suspension Bridge Model***" Project?

#	**Learning Experience**	**Average Rating / 10**
1	Telford was a good learning experience in terms of Problem-Solving	8.1
2	Telford was a good learning experience in terms of improving individual Essential Skills and Work Habits	8.1
3	Telford was a good learning experience in terms of team collaboration	8.6
4	Telford was a good learning experience in terms of development and application of shop skills	8.3
5	**Telford has good potential as a province-wide engineering challenge**	**8.9**

Wooden Model of Menai Bridge

The Scottish Diaspora Tapestry Scarborough Exhibition 2016

Many thanks for your attention

Questions and Comments?

Q: Slide 32 -- What was the error in the distance between the drive pin holes in the right vs. left connecting rods?

A: A touch less than a mm.