

Analyzing the Mechanics of Women's Roller Derby to Engage Introductory Physics Students

by

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Abstract:

We advocate using relevant, interesting and appealing examples for teaching introductory physics and consider women's flat track roller derby to be a particularly highly motivating context to young women in which to situate the study of kinematics, circular motion and friction. Using traditionally men's sports such as hockey, golf, football, dance and sailing to illustrate different physics principles has long been espoused as a helpful tool to increase student engagement. Women's roller derby is a fresh women-centric alternative sport to help physics teachers break out of this mold. Using data collected from the author's personal experiences we will show how various concepts from the NYSED Regents physics curriculum can be explored through the sport of roller derby. Sample questions for students are appended.

Bios:



Figure 1: Lead author, alias Farrah Daze Rage (sic. Faraday's Cage) #49, Lead Jammer, doing what she loves.
(Photo: Robert Krzaczek)

Amanda Dolan, born and raised in Rochester, NY, graduated from the State University of NY at Buffalo with a B.A. in Physics in 2003. In 2004 Amanda began studying for her Masters in Physics Education at Buffalo State College under the guidance of Dr. Dan MacIsaac. In 2009 Amanda joined Roc City Roller Derby and donned the pseudonym Farrah Daze Rage. Thinking about physics as she skated came so naturally she decided to focus on roller derby as her master project. Amanda currently runs a daycare out of her home while she works with a colleague to start a new public school in Rochester, NY. She would also like to thank Roc City Roller Derby and all its members for helping her and participating in this research.

Kelly Hebden, is also a graduate of the University at Buffalo physics program for future teachers, and also completed her M.S.Ed. in Physics Education from Buffalo State in 2006.

Dan MacIsaac is an Associate Professor at Buffalo State in the Department of Physics who coordinates the graduate physics teacher preparation programs. He has been inline skating only once ever while on sabbatical visiting Professor Eugenia Etkina of Rutgers University, together with her graduate students and alumni of her Masters degree program in physics teacher preparation at Rutgers University.

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Background:

Angell, Guttersrud and Henriksen (2004) found that students, especially female students, consider physics to be one of their most difficult subjects. They also found that physics students find developing a sound understanding of physics concepts to be both essential and difficult. This perceived complexity of physics topics by students is a good reason for physics educators to strive to showcase physics principles in new and interesting situations that can increase engagement for all students. Hatch and Smith (2004) report the use of sports examples in physics showed positive student responses. The sports most commonly used for instruction are traditionally male, and could leave female students feeling overlooked. Hence, women's flat-track roller derby: An up and coming, fast paced, hard hitting, all-women's sport sometimes touted as being one of the fastest growing sports in America.

Since modern flat track roller derby reentered the public sports scene in 2001 there has been little physics literature written on the topic. However, relatedly Eugenia Etkina (1998) used rollerblades to introduce basic kinematics to her students and then used that foundation to expand their knowledge into the more complicated areas of curvilinear and circular motion, inertia and centripetal force. Student interviews allowed her to record the positive effects the rollerblading activity had on her students. After Etkina's rollerblading unit, her students were able to "see physics everywhere."

Both NY State Education Department's Regents Physical Setting / Physics Core Curriculum <<http://www.p12.nysed.gov/ciai/mst/pub/phycoresci.pdf>> and the Next Generation Science Standards <http://www.nextgenscience.org/search-standards-dci?field_idea_tid%5B%5D=138> for the physical sciences require students to collect, represent, tabulate and interpret motion data, perform kinematics calculations determining velocity and acceleration, determine coefficients of friction, analyze interactions between objects, analyze forces via free body diagrams and use Newton's laws to determine motion.

Methods:

These ideas can be rendered more approachable to HS women in the context of questions about roller derby behaviors like "How fast do we skate?" and "How fast can we stop?" The lack of public knowledge concerning typical measurements for derby phenomena forced the authors to conduct several experiments. To make the experiments repeatable for students and teachers on a budget, almost all data were collected using stopwatches and a chart of the standard track with path lengths as shown in figure 2. According to WFTDA, the circumference of the inside line measures 148.5 ft. On the other hand, the circular crossover path is 178 ft. Calculated speeds were verified using an inexpensive toy radar gun well known to the physics teaching community, the \$69.99 Hot Wheels Radar Gun <http://service.mattel.com/instruction_sheets/j2358-0920.pdf> with which speed data were confirmed at the end of straightaways, pointing the gun at the skater's chest.

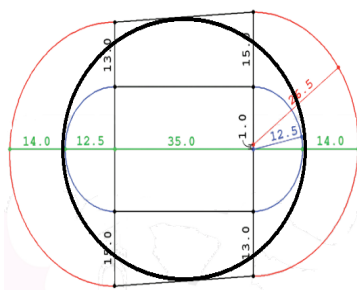


Figure 2: This image shows the dimensions of the Regulation track for Women's Flat Track Roller Derby Association, all dimensions are in feet. The thick black line shows the path followed by TaTa as she skated with crossovers. The inside line is shown in blue on the turns and black on the straightaways shows the path she skated when sculling. (Image credit: WFTDA WILL WE NEED THERE PERMISSION TO USE THIS?)

Average speeds and two different skating styles: Crossovers vs. Sculling

In roller derby, skaters are always accelerating or decelerating. Skaters generally accelerate by pushing off of the floor with their skates. Skaters use a combination of crossovers and sculling to gain and maintain speed. Crossovers are when the skater picks up her outside foot to step over the inside foot to push herself toward the center of the track. Sculling is when the skater keeps all eight wheels on the track and uses a sideways pushing motion to propel herself forward.



Figure 3: This picture shows a typical derby stance, low and centered, as Toxin Dioxin uses crossovers to speed around the track
(Photo: Robert Krzaczek)



Figure 4: Crossovers. JoJo Thrasher, using crossovers to skate around the track.
(Photo: Robert Krzaczek)



Figure 5: Sculling. Karmalized, sculling to propel herself around the track.
(Photo: Robert Krzaczek)

Using both the stopwatch and the radar gun I was able to find the speed while sculling and crossing over.

	crossovers	sculling
	Δt	Δt
lap 1	13 seconds	12 seconds
lap 2	10 seconds	12 seconds
lap 3	9 seconds	10 seconds
average	10.6 seconds	11.3 seconds

Table 1: Lap Times Recorded with Stopwatch, same skater but two different paths and techniques. When using crossovers, TaTa followed a circular path and when sculling she followed the inside line of the track.

These data lets us compare the two styles of skating. At first glance, the similarity in the times for each lap could lead one to believe that there is little difference between the two skating styles. However, TaTa followed two different paths when using these two different skating styles. In the first trial, using constant crossovers, she was following a circular path as she skated on the inside line at the turns and toward the outside line on the straightaways. In the second trial, TaTa was hugging the inside line as she sculled around the track.

To clarify the relationship between speed, distance and time using the two skating styles, students must calculate the speed of the skater and compare the following data.

	Stopwatch		Hot Wheels Radar Gun	
	crossovers	sculling	Crossovers	Sculling
Average Speed	5.1 m/s	4 m/s	5.4 m/s	4.4 m/s

Table 2: When following the shorter path and sculling, TaTa's average speed was slower than when she was using crossovers and following a longer path. The radar gun shows a similar comparison (though higher, likely due to faster than average velocity during the straightaway) between sculling and crossovers.

Skating and Centripetal Acceleration through the curves

Using the information provided above, we can find the centripetal acceleration and the coefficient of friction for each skating method.

For example, let us find the centripetal acceleration and coefficient of friction for a skater using crossovers to skate around the curved end of the track. First we will need a Free Body Diagram of the skater.

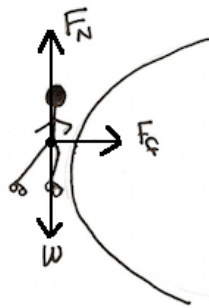


Figure 6: This free body diagram shows the forces acting on a skater as she skates around the track.

To find the centripetal acceleration we must first find the radius of the circular path the skater was traversing. Looking at Figure 2 we find the radius to be 30 feet or 9.14 meters. The velocity we use here was for the faster crossover skater.

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{(5.4m/s)^2}{9.14m}$$

$$a_c = 3.2m/s^2$$

Using the acceleration we can find the force of friction as the skater skates around the track.

$$\Sigma F_x = ma_c = F_f$$

$$F_f = ma_c$$

$$F_f = 77.1kg * 3.2m/s^2$$

$$F_f = 247N$$

To find the normal force we need the skater's weight. The skater's mass is 77.1kg.

$$\Sigma F_y = ma = 0 = w * F_N$$

$$\therefore w = F_N$$

$$\therefore mg = F_N$$

$$77.1kg * 9.8m/s^2 = F_N$$

$$F_N = 755.58N$$

Finally, we can calculate the coefficient of friction using the normal force and the force of friction.

$$F_f = \mu_f F_N$$

$$247N = \mu_f * 755.58N$$

$$\mu_f = .33$$

	Skater mass (m)	Normal force (F _N)	Average velocity (\bar{v})	Radius (r)	Centripetal acceleration (a _c)	Force of friction (F _f)	Coefficient of friction (μ _f)
Units	kg	N	m/s	m	m/s ²	N	
Crossovers	77.1	755.58	5.4	9.14	3.2	247	.33
Sculling	77.1	755.58	4.4	9.14	2.1	163	.22

Table 3: This table displays all data and calculations of the centripetal acceleration and coefficient of friction for both crossover and sculling skating.

Falling and the trajectory of objects in circular motion

Falling skaters are something a spectator will see many times at a derby bout and those observations provide a perfect opportunity to demonstrate the difference between angular acceleration and angular velocity. A fallen skater is no longer accelerating towards the center of the track, instead, she will slide to the edge, or perhaps even off the track. This is because her angular acceleration is now zero so she will no longer have any force pushing her towards the center of the track. Since the direction of angular velocity is tangential to the circular path the skater is traveling on, students can predict which spectator will get a flying derby girl in their lap after a fall and slide into the crowd.



Figure 7: This photo shows a fallen skater sliding off the track on both knees (the “rock star” fall). (Photo: Robert Krzaczek)

The skater in red is at the mercy of her own inertia as she slides away from the track. However, the skater in blue, Wolf Blitzkreig, is still on her skates and can shift her center of mass to maintain enough angular acceleration to keep her position on the track. This is very similar to the traditional demonstration of whirling a string with a ball at the end around your head and cutting the string to watch the ball fly off away from your hand. In the roller derby example the ball is the red skater and the vector of centripetal acceleration caused by skating can represent the string. Once a skater is no longer up and skating she flies off in the direction of her velocity just prior to her fall. This is a good place to compare the trajectories of the skater's slide after a fall when she falls on the curved portion of the track versus the straight portion of the track.

Controlled falling: One knee vs. two knee (rock star) falls

Studying falls and stops in roller derby provide a good example of friction bringing an object in motion to a halt. By recording the stopping time and stopping distance we can compare the magnitude of deceleration for various falls (and later intentional stops). Shockin’ Audrey demonstrated two controlled falls with recorded stopping distance and time. A stopwatch was used to record the time it took her to come to a complete stop after she hit the floor. The skate floor was constructed of one by one foot plastic tiles which were counted to find an approximate stopping distance once Shockin’ had come to a complete stop.



Figure 8: Susan B. Agony, performing a one-knee fall
(Photo: Robert Krzaczek)



Figure 9: Scarlett Bloodletter, performing a two-knee "rock star" fall
(Photo: Amanda Dolan)

	Time (seconds)		Distance (meters)	
	One-Knee Fall	Two-Knee Fall	One-Knee Fall	Two-Knee Fall
Trial 1	7.2	2.72	4.3	1.67
Trial 2	7.3	2.52	4	1.53
Trial 3	8.7	2.79	4.3	1.46
Average	7.7	2.6	4.2	1.6

Table 4: This table displays data for how long it takes for a skater to come to a complete stop while performing a one-knee and a two-knee fall as well as how far that skater slides after making contact with the floor.

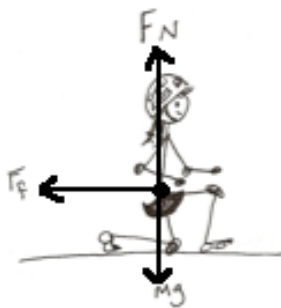


Figure 10: Free Body Diagram for a one knee fall

The data in the above chart provides teachers with appropriate values to formulate physics examples related to roller derby. Finding the initial velocity the skater was moving at just before she began her deceleration due to the fall is one example of a physics problem to solve. Sample problems using these data can be found in the appendix. A correct free body diagram is necessary to be sure students have correctly summed the forces in all directions.

Note: We are simplifying the problem to a point FBD, putting all forces on the skater's center of mass, ignoring the fact the skater is an extended object whose center of mass is offset from the points of contact with the floor. It is traditional to so simplify in one and two dimensional motion and then much later to complicate the models by allowing tipping at a later point (often during rotational dynamics).

Controlled Stopping (without falling): Toe, T-, Plow and Tomahawk stops

Skaters have numerous methods for stopping at their disposal. We recorded and analyzed the stopping times and distance for several of these methods. Shockin’ Audrey performed four different types of stops. Author Farrah Daze Rage also demonstrated a stop. Here are our data for these ten stops.

	Time (seconds)					Distance (meters)				
	Toe Stop	T-Stop	Plow Stop Audrey	Plow Stop Rage	Tomahawk	Toe Stop	T-Stop	Plow Stop Audrey	Plow Stop Rage	Tomahawk
Trial 1	3.63	2.51	3.07	1.46	0.97	9.45	5.49	8.23	4.27	2.74
Trial 2	3.70	2.41	2.79	1.81	1.32	9.45	6.71	7.92	5.03	3.35
Trial 3	3.98	2.51	2.76	1.60	1.18	9.75	5.49	6.71	4.57	2.74
Average	3.77	2.48	2.87	1.62	1.16	9.65	5.89	7.62	4.62	2.95

Table 5: Comparing Four Methods of Stopping. This table displays data for how long it takes for a skater to come to a complete stop as well as how far that skater slides after initiating the stop.



Figure 10: The Toe Stop. JoJo Thrasher (#800, middle) drags her toe-stop, changing her speed to dodge an incoming blocker. (Photo: Robert Krzaczek)



Figure 11: T-Stop. Camraderay (#24 on the right side of the photo), performing a t-stop. (Photo: Robert Krzaczek)

The science of the toe stop could be a paper all on its own. The variables that could be included in an extensive study of toe stops are many. Toe stops are made from many different materials, and in different shapes. Sin City Skates, a popular site for buying roller derby equipment, sells fourteen different types of toe stops. The length of the toe stop can be short and close to the skate, or long and near the floor. The toe stop rubs away every time it is used; this wear and tear changes the toe stop and also affects stopping ability. Finally, the skater's technique also influences the effectiveness of stopping. The basic method of stopping using a toe stop is to extend one skate behind the other, dragging the toe stop on the ground. The harder the skater pushes the toe stop into the ground, the quicker she will slow down.

The T-stop is a common method for stopping in crowded areas since it allows the skater to keep her legs close together. To execute this stop, the skater must place one of her skates perpendicular to the rolling skate. The stopping power from the t-stop comes from the skater pushing the wheels of the perpendicular skate down on the ground. The T-stop brings the skater to a stop about one second faster and in almost half the distance when compared to using the toe-stop. Since roller derby is a game where speeding up and slowing down happens constantly, having an effective method of stopping quickly is crucial for serious skaters.

As with the toe stop, there is an interesting materials aspect to the T-stop that can have a significant impact on the skater's ability to stop. A quick glance back at Sin City Skates' website shows more than forty different types of wheels available for sale. Here too, the condition of the wheels is important to note.



Figure 12: Plow stops. Jacky Spades (#8, far right) and Poplockndropya (#32, center) are performing plow stops to slow opposing jammer, GVAR (with gold helmet cover), (Photo: Robert Krzaczek)

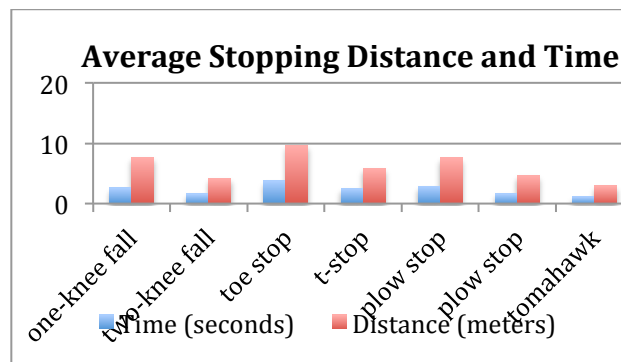


Figure 13: A Tomahawk Stop. JoJo Thrasher (#800, far left) performing a tomahawk stop. Both skaters' direction of motion is to the left. (Photo: Robert Krzaczek)

The plow stop is more than just a method of stopping. It is also a method for positionally blocking other skaters. To execute a plow stop the skater must skate with a wide, low stance, bending at her knees. She pushes the innermost wheels of each skate into the floor while turning her toes in. This causes her to slow down quickly and, depending on her stance, can also act as a barrier on the track, impeding skaters who hope to glide past her.

Data collected on two skaters show differences in plow stopping with varying levels of success. The difference in effective use of the plow stop can be seen in the differences between Audrey and Rage's average stopping time and distance. Each skater has her preferred stopping method, and it is usually the one she is most proficient at.

The tomahawk is one of the most immediate ways to come to a controlled stop while on skates. In contrast to the plow stop, the tomahawk does not require the skater to spread out on the track, so this stop can be executed in tight packs without fear of tripping other skaters. The tomahawk is also one of the most difficult stops for a skater to learn. To do a tomahawk stop the skater must first transition from skating forward to skating backwards. The skater will lean forward, in the direction opposite to her direction of motion, with her weight on her toes. Then she lifts up off her heels and rear wheels to her toe stops. Without any wheels rolling and only two toe stops dragging under her, the skater skids to a stop very quickly. The tomahawk is the fastest controlled way to stop when compared to all other methods discussed in this paper.



Graph 1: This graph compares the average stopping distance and time for all falls and stops described in this paper.

Calculating Accelerations and Friction Coefficients for Falling and Stopping

Using the information provided above, we can find the force of friction and the coefficient of friction for each falling and stopping method.

For example, let us find the force of friction and the coefficient of friction for stopping when dragging a toe stop. First we will need a free body diagram of a skater coming to a halt. We will use the time and distance recorded for trial 2.

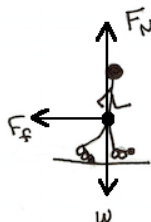


Figure 14: Free Body Diagram of Skater Stopping with a Toe Stop (she drags her toe stop to come to a halt).

To find the normal force we need the skater's weight. The skater's mass is which is 77.1kg.

$$\begin{aligned}w &= mg \\w &= 77.1\text{kg} * 9.8\text{m/s}^2 \\w &= 755.58\text{N}\end{aligned}$$

We know that the sum of the forces in the y-axis must be zero because the skater is not accelerating in the y-axis.

$$\begin{aligned}F_y &= 0 = F_N + (-w) \\ \therefore F_N &= w \\ F_N &= 755.58\text{N}\end{aligned}$$

We have learned that a skater with a mass of 77.1kg comes to a full stop using her toe stop in 9.65m and 3.71s. Using this information we can find the coefficient of friction between the floor and the toe stop.

First we will find the initial velocity. We can do that by calculating the average velocity and since the final velocity is 0m/s the initial velocity can be calculated in two steps. Note in introductory mechanics it is common to assume uniform acceleration, as we are doing here.

$$\begin{aligned}\bar{v} &= \frac{d}{t} = \frac{9.45\text{m}}{3.7\text{s}} = 2.6\text{m/s} \\ \bar{v} &= \frac{v_f + v_i}{2} \\ 2.6\text{m/s} &= \frac{0 + v_i}{2} \\ v_i &= 5.11\text{m/s}\end{aligned}$$

Once we have the initial velocity we can find the acceleration.

$$\begin{aligned}a &= \frac{\Delta v}{t} = \frac{v_f - v_i}{t} \\ a &= \frac{0 - 5.11\text{m/s}}{3.7\text{s}} \\ a &= -1.4\text{m/s}^2\end{aligned}$$

Using the acceleration we can find the force of friction that is causing the skater to slow to a stop.

$$\begin{aligned}\Sigma F_x &= 0 - F_f = ma \\ -F_f &= ma \\ -F_f &= 77.1\text{kg} * (-1.4\text{m/s}^2) \\ F_f &= 106\text{N}\end{aligned}$$

Finally, we can calculate the coefficient of friction using the normal force and the force of friction.

$$F_f = \mu_f * F_N$$

$$106N = \mu_f * 755.58N$$

$$\mu_f = 0.14$$

Repeating the above technique, we can calculate all of the above values for each stopping and falling scenario described throughout this paper, in Table 6.

		Time (sec)	Distance (m)	Mass (kg)	Normal force (N)	average v (m/s)	Final velocity (m/s)	Velocity (m/s)	acceleration (m/s ²)	Force of friction (N)	Coefficient of friction
One Knee	1	7.2	4.3	77	756	0.6	0	1.19	-0.2	12.79	0.017
	2	7.3	4	77	756	0.5	0	1.1	-0.2	11.57	0.015
	3	8.7	4.3	77	756	0.5	0	0.99	-0.1	8.76	0.012
	average	7.73	4.2	77	756	0.5	0	1.1	-0.1	11	0.01
Two Knee	1	2.72	1.67	77	756	0.6	0	1.23	-0.5	34.81	0.046
	2	2.52	1.53	77	756	0.6	0	1.21	-0.5	37.15	0.049
	3	2.73	1.46	77	756	0.5	0	1.07	-0.4	30.21	0.04
	average	2.66	1.55	77	756	0.6	0	1.2	-0.4	34.1	0.05
Toe Stop	1	3.63	9.45	77	756	2.6	0	5.21	-1.4	110.6	0.146
	2	3.7	9.45	77	756	2.6	0	5.11	-1.4	106.4	0.141
	3	3.98	9.75	77	756	2.4	0	4.9	-1.2	94.91	0.126
	average	3.77	9.55	77	756	2.5	0	5.1	-1.3	104	0.14
T-Stop	1	2.51	5.49	77	756	2.2	0	4.37	-1.7	134.4	0.178
	2	2.41	6.71	77	756	2.8	0	5.57	-2.3	178.1	0.236
	3	2.51	5.49	77	756	2.2	0	4.37	-1.7	134.4	0.178
	average	2.48	5.9	77	756	2.4	0	4.8	-1.9	149	0.2
Plow - Audrey	1	3.07	8.23	77	756	2.7	0	5.36	-1.7	134.7	0.178
	2	2.79	7.92	77	756	2.8	0	5.68	-2	156.9	0.208
	3	2.76	6.71	77	756	2.4	0	4.86	-1.8	135.8	0.18
	average	2.87	7.62	77	756	2.7	0	5.3	-1.8	142	0.19
Plow - Rage	1	1.46	4.27	73	711	2.9	0	5.85	-4	290.9	0.409
	2	1.81	5.03	73	711	2.8	0	5.56	-3.1	222.9	0.313
	3	1.6	4.57	73	711	2.9	0	5.71	-3.6	259.2	0.364
	average	1.62	4.62	73	711	2.9	0	5.7	-3.5	258	0.36
Tommie	1	0.97	2.74	77	756	2.8	0	5.65	-5.8	449	0.594
	2	1.32	3.35	77	756	2.5	0	5.08	-3.8	296.5	0.392
	3	1.18	2.74	77	756	2.3	0	4.64	-3.9	303.4	0.402
	average	1.16	2.94	77	756	2.6	0	5.1	-4.5	350	0.46

Table 6: This table displays all data used to calculate the coefficient of friction for each type of stop and fall.

Conclusion

Using practical examples such as sports to help teach physics helps students to better grasp the new and complex concepts that are part of the Regents physics curriculum. Including roller derby scenarios with today's commonly used sports scenarios to teach physics can add something new and unique and also engage more female students due to female dominance in the sport of roller derby.

My goal with this paper was to introduce roller derby to the physics teaching community and provide ideas for physics questions and a basis for numerical values to use in those questions to keep the scenarios valid. I also hope I was able to show that there is more to roller derby than just kinematics; materials science is one of many other areas that could also be explored if students showed interest.

Engaging students is important, and helping students develop an authentic understanding of the physical world should be our goal. With more scenarios for practice questions we increase the chance that more students will see physics everywhere.

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Appendix A - A Brief Introduction to Roller Derby

"It's like Wayne Gretzky said: "Skate to where the puck is headed, not to where it's been" ...except of course, in our case the "puck" is the opposing jammer, or a blocker we're trying to control...and it has a mind of its own. Roller derby is so much better than hockey."
Resident Eva (Roc City Roller Derby)

I often speak with people who are unaware of the recent resurgence of roller derby, yet many people remember roller derby's initial incarnation. With banked tracks, high speeds, minimal safety equipment and skaters with strong personae it is difficult to forget the roller derby created and promoted by Leo Seltzer in the 1930s. Barbee and Cohen's book, *Down and Derby* (2010) delves into roller derby's roots and how the 1970s gas crisis and the increased theatrical nature of the roller derby caused the sport's popularity to wane. Fortunately, in 2001 a group of people in Texas gathered to begin roller derby's meteoric comeback. Joulwan, founder of the Texas Rollergirls, chronicled the resurgence of roller derby in her book, *Roller Girl* (2007.)

These days the most common form of roller derby is played on a flat track and is regulated by the Women's Flat

Track Derby Association (WFTDA.) Rules for the sport can be found at wftda.com/rules. Two thirty-minute halves are divided into an indeterminate number of “jams” which can last up to two minutes each. At the start of each jam eight blockers, four from each team, line up together forming “the pack.” One jammer from each team starts behind the pack and earns one point for each opposing skater they pass legally and inbounds. Throughout the jam, the blockers are positioning themselves to help their jammer and stop the opposing team’s jammer with a variety of hits, blocks and assists. After the jam ends, the skaters leave the track and each team has 30 seconds to get a fresh lineup of skaters out for the next jam.

Brenda "Skater Bater" Delano wrote a short and concise article for *American Fitness* (2010) explaining the basics of roller derby. A first time fan will most likely find roller derby very confusing, but with Delano's breakdown of the sport, any fan can get up to speed in just a few minutes. Delano describes the basic rules and game-play of the sport, as well as the intense effort skaters must put forth in training.

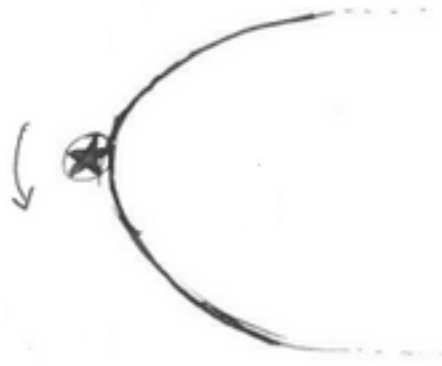
Appendix B - Sample questions

1. A 65-kilogram roller derby skater skates around the track in a horizontal circle with a radius of 9 meters. The diagram in your answer booklet represents the motion of the skater. The skater maintains a constant speed of 5 meters per second.

A. Calculate the magnitude of the centripetal acceleration of the skater.

Answer: $a_c = 2.8 \text{ m/s}^2$

B. On the diagram below, draw an arrow showing the direction of the centripetal force acting on the skater when it is at the position shown.



2. Calculate the time required for a 200-newton net force to bring a 70-kilogram skater initially traveling at 5 meters per second to a full stop.

Answer: $t = 1.75\text{s}$

3. A roller derby skater weighs 750 newtons. The skater races around a cement track, crossing over the whole time. The coefficient of friction is 0.3.

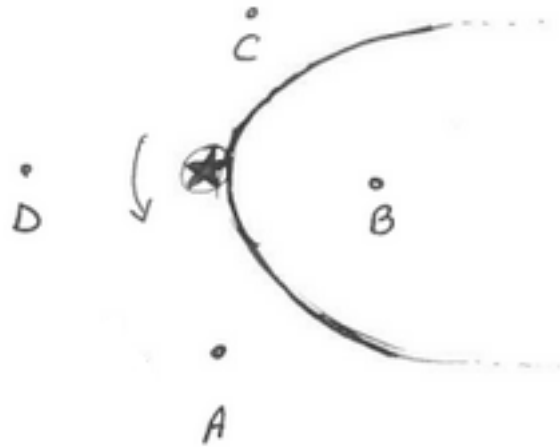
A. Determine the magnitude of the normal force exerted by the cement floor on the skater’s wheels as the skater skates across the horizontal surface.

Answer: $F_N = 750\text{N}$

B Calculate the magnitude of the force of friction acting on the wheels as the skater skates across the horizontal, cement surface.

Answer: $F_f = 225\text{N}$

4. The diagram below shows a skater, represented with a star, skating counter-clockwise at a constant speed around a horizontal track.



At the instant shown, the centripetal force acting on the skater is directed toward which point?

Answer: B

5. A 60-kilogram roller derby skater skates around the track during a bout. The radius of her path is 9 meters. She completes 3 laps in 30 seconds.

A. Determine the speed of the skater.

Answer: $v = 5.65\text{m/s}$

B. Calculate the magnitude of the centripetal force on the skater.

Answer: $F_c = 37.7\text{N}$