Work in Progress: Use of Storytelling in Mechanics Assessments

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Introduction

As a new faculty member at the University of Northwestern - St. Paul, I teach our mechanics course sequence. In learning to write exams, I drew inspiration from Dr. Guy Genin, professor of mechanical engineering at Washington University in St. Louis, who was famous among the undergraduate engineering students for writing themed exams in his dynamics courses [1]. Over the last year, I have taken this idea and made it my own, writing story-based exams for a calculus-based Physics I, Statics & Dynamics, and Mechanics of Materials. For me, having a story in mind while writing an exam can ease the process of coming up with questions and is a means of building rapport with my students. Themes have ranged from imagined adventures of a young cousin to familiar movies to building a playground.

Prior work has pointed to storytelling as a way to provide authentic context for mechanics problems that engage students in meaningful ways to help them learn material and link it to real-world applications [2, 3, 4]. Overall, most students respond well to story-based exams (Fig. 1). For students the stories serve two functions: they provide context for the questions posed that are consistent from problem to problem and they inject a bit of humor into the exam that can ease students' anxieties.

By providing a storyline to an exam, even when problems have different foci, students are enticed to follow along. For example, in a movie-themed exam, different questions might come from different parts of the movie. If students are familiar with the movie, they already feel like they know something about the exam. This can boost student confidence. Students do not have to figure out the context of the question and can instead focus on what they need to solve.

Exams typically induce increased stress for students. Stories can provide some humor on test day and help to relieve some of this stress. Some of my students even approach exam days with excitement because they want to know what the story will be. In review sessions ahead of exams, "What's the theme?" is usually the first question from students.

Approach to Developing Exams

Most exams take 4-6 hours to develop once I start writing. The first step is always identifying and prioritizing the concepts that need to be tested. Once that is set, I try to identify a theme that will be a good match to the material. If I use a movie theme, I will often re-watch the movie and make notes on scenes or ideas that map well to my list of concepts. Typically, I try to use scenes that allow me to write multi-part problems and reduce the number of figures that need to be drawn. Writing the problems themselves is typically not much different from writing a standard exam. Even when superheroes are involved, I try to keep dimensions, weights, forces within realistic parameters. To reduce development time, I have been able to repurpose some drawings for subsequent exams (eg. the Statics & Dynamics exam in Appendix B was re-written as a physics exam in Fall 2017), and I use the same final exams each semester. Samples of past exams are available in Appendices B-E.

When selecting a theme, there are several potential approaches. The calendar can suggest storylines – such as an imaginative costumed child in late October or movies like How the Grinch Stole Christmas in December. Alternatively, movies targeted to families that involve action or physical humor work well for physics and dynamics exams. For example, the traps in Home Alone worked well for a rigid body kinematics and kinetics exam (Appendix E). Movies are more difficult for mechanics of materials, but the course frequently focuses on designing for safety. Thus, a theme that puts students in the mindset of designing a building or a playground – analyzing loadings and associated deformations – feels like an authentic context. I have also taken suggestions from students for themes. One of these was a farm theme for a mechanics of materials exam (Appendix D), in part because the student recognized many of the failure modes from growing up on a farm.

Student Response to Story-based Exams
To gather anonymous feedback from students on their response to themed exams, a short survey was developed. The survey questions (Appendix A) generally focused on overall like/dislike of the exams along with some of the advantages and pitfalls. Of 71 surveys sent out, 52 were completed (73% response). Students were asked whether they liked exams with a theme/story on a 100-point slider where 0 was "Not at all," 50 was "Ambivalent," and 100 was "Very Much." With 50 responses, students rated story exams at 78 ± 21. Exams with a storyline have also held students' attention with 46% reporting that they had told someone outside of engineering about taking a themed exam.

Nineteen students rated exams with a story at 90 or above (eleven 100's), indicating a strong positive response. The top three reasons students cited for liking exams were as follows: "They make me laugh" (71%), "They provide context for problems" (67%), and "I don't have to adjust to a new context for each problem" (60%).

The primary advantages of exams with a story were continuity of context from one problem to the next and stress relief via humor.

> "Themes help a test feel like one cohesive unit as opposed to several random problems"
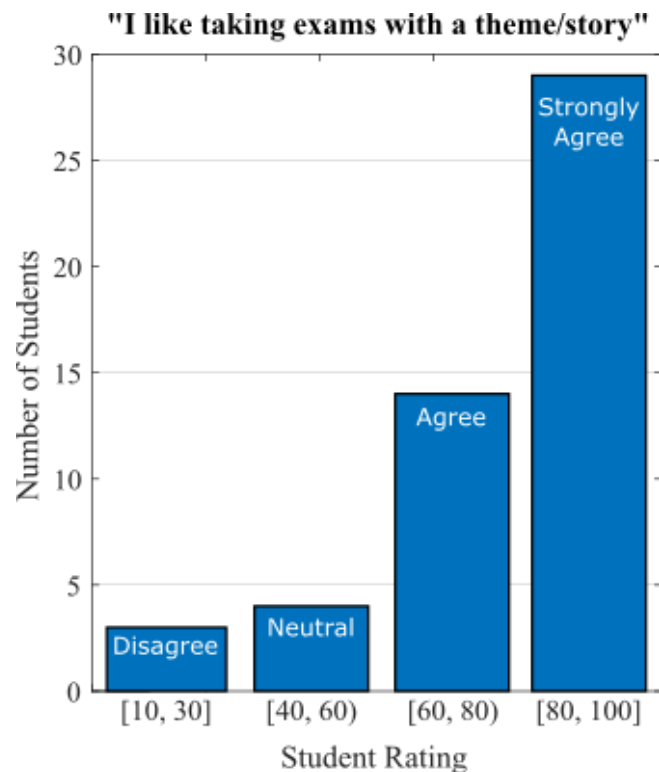
"They [themes/stories] distract us from the cold, unfeeling and uncompromising material we actually have to navigate and solve"

Students also identify the benefit of familiarity with the story in understanding what may be happening in a problem.

"It helps me visualize the problem if I already have an idea of what it would look like, and helps me know if my answer is somewhere in the ballpark of what it should be."

Only three students rated themed exams at 30 or below, indicating a strong dislike of them. Overall, students' biggest concerns about these exams were "I don't always know what is being asked" (42%) and "I'm not sure what to solve since several concepts may be needed" (31%).

The biggest critique from students was that questions and figures sometimes lack clarity. Feedback from several students suggested that including simple drawings more typical of an engineering textbook help to clarify problems. One student's take on this is below.

"Make sure that the object in question is clear from an engineering standpoint. The best themed exams are when there is a theme/story throughout, but the pictures are diagrams of beams and simple shapes, not nice pictures that go exactly with the story. This makes understanding what is to be solved and what situation is actually occurring much easier to understand."

Another note of caution:

"Themed exams can be fun, but it matters how well the scenario fits the desired topic or method. Some have been the final step in grasping a concept, while others have left me with more questions than answers about a topic."

One factor that has been difficult to tease out is whether questions lacking clarity stems primarily from the use of stories or is simply a byproduct of my own learning curve as a new faculty member writing exams for the first time.

Conclusions
Overall, most students have enjoyed themed exams. Including a storyline on an exam can make the problems seem more cohesive for students, while providing a context and injecting some humor. Writing a story-based exam does not have to take more time than a standard exam, just a bit more attention to the relationship between problems. Illustrations for problems can be time consuming, but based on student feedback, simplifying drawings may be advantageous for both accurate student interpretation and reduction of instructor time spent.

References

[1] Dept. Mechanical Engineering and Material Science, "Dynamics Exams Database," Dynamics. [Online]. Available: https://classes.engineering.wustl.edu/mems255/exams.html. [Accessed: 27-Apr-2018].

[2] S. Moseley, "One Paragraph and a Few Simple Questions – Giving Statics Problems Human Context," in *Proceedings of the American Society for Engineering Education Annual Conference and Exposition, ASEE 2017, Columbus, OH, USA*.

[3] R. Homolka and G. Stephens, "A Triple Play: Mathematics, Baseball, and Storytelling," in *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, 2010, Louisville, KY.

[4] D. Chesney, "Big Fish: The Lost Art of Story-telling in the Engineering Classroom," in *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, 2006, Chicago, IL.

Appendix A: Themed Exams Student Survey and Numerical Responses

1. I like taking exams with a theme/story.

Not at all	Ambivalent	Very much

2. I like themed exams because:
   - ☐ They calm me down [35%]
   - ☐ I feel like I know something about the question before solving [37%]
   - ☐ They provide context for problems [67%]
   - ☐ I feel more confident [15%]
   - ☐ They make me laugh [71%]
   - ☐ It helps me understand why a question matters [48%]
   - ☐ I don't have to adjust to a new context for each problem [60%]
   - ☐ They build camaraderie with my instructor and classmates [37%]
   - ☐ Other: _____

3. I dislike themed exams because:
   - ☐ I find the themes distracting [10%]
   - ☐ I'm not sure what to solve since several concepts may be needed [31%]
   - ☐ I don't always know what is being asked [42%]
   - ☐ I feel uncertain if I don't recognize the theme/story [19%]
   - ☐ I feel left out by some themes [6%]

4. Do you have a favorite exam theme?

5. What else would you like me (another instructor considering writing themed exams) to know?

6. Which of these describe you?
   - ☐ 1st year [31%]
   - ☐ 2nd year [46%]
   - ☐ 3rd year [21%]
   - ☐ 1 class with instructor [37%]
   - ☐ 2+ classes with instructor [58%]
   - ☐ Electrical/Computer [15%]
   - ☐ Mechanical [63%]
   - ☐ Civil [13%]
   - ☐ I told someone outside of engineering about taking themed exams (eg. parents, siblings, roommates, etc.) [46%]
   - ☐ Other (please specify): _____

Appendix B: The Incredibles Themed Exam: Point Mass Kinetics and Kinematics

Engineering 2105 — Statics and Dynamics   Name: _____

Exam II —Ch.8-14

Closed Book & Notes — Centroid and Moment of Inertia Tables provided, 1 8.5x11" equation sheet allowed (65 minutes)

Even though this test is multiple choice, you must clearly show your work to solve the following problems, and make use of **Free Body Diagrams** wherever appropriate.

1. Dash is so fast that he takes approximately 58 strides per second. This tends to generate a lot of friction on his clothing. With each stride, his arm rubs his suit for 4-inches <u>each direction</u> (swing forward, swing back) with a friction force of 0.15 lb.


$f_k = 0.15$ lb

   a. If Edna made sure that the coefficient of kinetic friction for this suit material is very low, $\mu_k = 0.05$, what is the average normal force between Dash's arm and his body?
   b. For each stride, how much energy does this friction force dissipate (ft-lb)?
   c. Over one second, how much power does this friction dissipate (ft-lb/s)?
   d. Using the power dissipation in part b, how much energy does just arm friction dissipate if Dash runs for one minute? Convert this to kCal (Calories listed on food labels) using 1 kCal = 3.088 ft-lb.

2. While attempting to escape Syndrome's thugs, Violet (m = 41 kg) and Dash (m = 27 kg) run away gerbil-ball style in Violet's force field (massless).
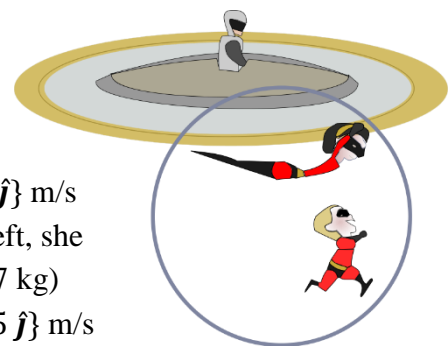
   a. Dash and Violet have a velocity of $\{36\hat{\imath} + 12\,\hat{\jmath}\}$ m/s relative to a large cliff. As Violet looks to her left, she spots a guard in a velocipod (combined m = 227 kg) approaching them with a velocity of $\{-2\hat{\imath} - 25\,\hat{\jmath}\}$ m/s <u>from her perspective</u>. What is the velocity of the guard with respect to the cliff (m/s)?
   b. What is the total linear momentum of the system (N·s)?
   c. What is the total kinetic energy of the system?

3. Using the provided **_mass moment of inertia_** table, approximate Edna as a combination of a rectangular prism, a cylinder, and two cones. Compute Edna's mass moment of inertia about a central vertical axis (kg·m²). Use the table below to keep track of your pieces.
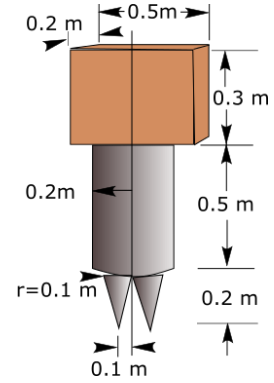
Segment	Mass (kg)	Segment I_x formula (from table)	Dimension 1 (m)	Dimension 2 (m)	Segment I_x (kg·m²)	d (m)	I_x about central axis (kg·m²)
Head	10		0.5	0.2		0	
Torso	20			N/A		0	
Leg	4	$\frac{3}{10}ma^2$	0.1	N/A			
Leg	4	$\frac{3}{10}ma^2$		N/A			
Total	38	-----------------	------------	------------	------------	---- --	

4. While at home with the babysitter, Jack-Jack rolls a ball at the wall (v_o = 4 m/s). The ball collides with the wall at a 30° angle to the wall, and the x-component of velocity after impact is 2 m/s.
   a. What is the final velocity of the ball after impact?
   b. What is the coefficient of this collision?
   restitution for
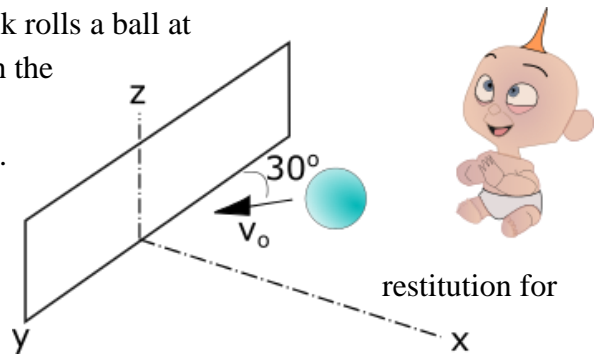
Appendix C: Thor Themed Physics I Exam: Kinetics

Physics 1201 – Physics for Engineers I   Name: _____
Exam II

Exam 2 has 100 total points. This exam is themed on Marvel's Thor. Thor comes from another world and his preferred weapon is a large square hammer that can only be wielded by someone who is worthy. Thor's brother Loki becomes his enemy following a series of revelations. List knowns and unknowns, identify the formulas you use, work out your solutions symbolically before plugging in numbers. Clearly show all of your work and box your final answers for each problem. Work out problems on engineering paper. Be sure to include problem statements. Include Free Body Diagrams as appropriate, not just where specifically requested.

1. Let the mass of Thor's hammer be 19.2 kg. It lands on a window-washing platform (m_p = 5.00 kg) on the edge of a building roof. The platform is attached to a massless cable over a frictionless pulley. Thor just manages to grab the cable and slides toward the edge with a constant speed.
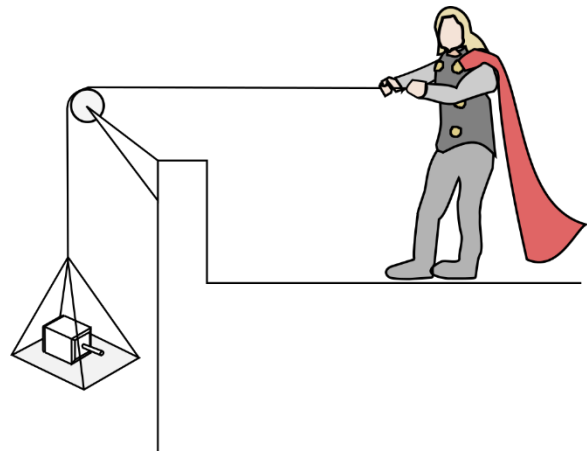
   A. What is the tension in the vertical part of the cable?

   B. What force does the cable exert on Thor?

   C. What force is the Newton's 3rd law reaction to the weight of the hammer?

   D. What force is the Newton's 3rd law reaction to the normal force on the hammer?

   E. If the coefficient of kinetic friction between Thor's feet and the rooftop is μ_k = 0.250, find Thor's mass.

2. Thor swings his hammer in a vertical circle to prepare for using it to fly. The mass of the hammer is 19.2 kg. The radius of the circle is 0.500 m.
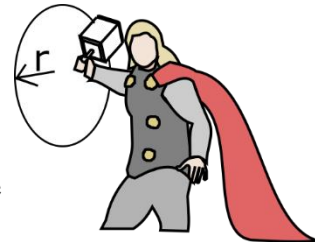
   A. What is the critical speed for the hammer to make it around the circle smoothly?

   B. If Thor spins the hammer with a tangential speed of 4.00 m/s, what force does Thor need to exert on the hammer when it is at the bottom of the circle?

   C. Compute the force of gravity between Thor's hammer and Asgard's planet. The mass of the planet is 6.45 (10^{23}) kg and its radius is 3.54 (10^6) m.

3. Thor is known in mythology as the "god of thunder" and can create storms by swinging his hammer in circle over his head. Suppose a bird (m = 0.500 kg) gets caught up in the wind and clouds swirling around. The bird has an angular velocity of ω = 0.800 rad/s and stays at a radius of R = 25.0 m from Thor's hammer.

R
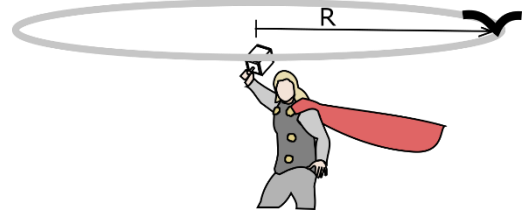
A. The storm stops suddenly and the centripetal force goes to zero. Draw a free body diagram of the bird, do not ignore air resistance.

B. What is the drag force on the bird at the instant the centripetal force goes to zero? Let $\rho C = 1/2$ and A = 3.25(10-3) m2.

C. If the bird hits something that stops its horizontal velocity and it is knocked unconscious. Find its terminal velocity as it falls.

4. Loki finds Thor's hammer and attempts to pull it toward himself. The hammer's sense of worthiness acts like a friction force with a very high coefficient ($\mu_{uw} \gg 1$) when someone unworthy tries to use it. Assume Loki has a mass of 68.0 kg and the coefficient of static friction between Loki and the ground is $\mu_s = 0.700$.
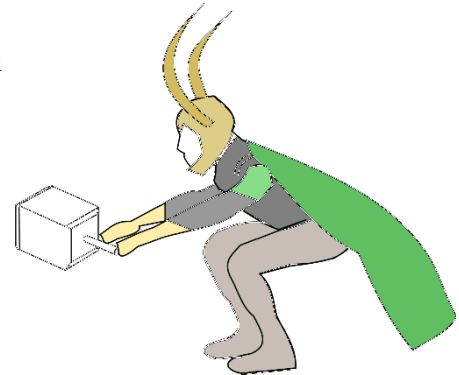
A. What is the maximum value of the static friction force (in N) between Loki and the ground?

B. What is the maximum force Loki can exert on the hammer? Explain.

C. Sketch a plot with the force Loki exerts on the hammer on the horizontal axis and the force the hammer exerts on Loki on the vertical axis. Assume Loki starts with 0.00 N and then increases the force linearly.

Appendix D: Farm Themed Mechanics of Materials Exam: Stress, Strain, Torsion

Engineering 2205 – Mechanics of Materials   Name: _____

Closed Book & Notes – Common Material Properties Table and Stress Concentration Factor Plots provided, one 8.5" x 11" equation sheet allowed (65 minutes). Complete two of the five questions that begin with an asterisk (*).

You must clearly show your work to receive credit and make use of Free Body Diagrams wherever appropriate.

1. The bale spear shown is used to lift and move large round hay bales (W=1100 lb).
    a. What is the resultant shear force on each spear? (8pts)
    b. What shear stress does each spear experience? (14pts)
    c. *If the spears attach to the support structure (3/16-in thick) with bolts (d = ¼-in.), what bearing stress does the support structure experience? (14 pts)
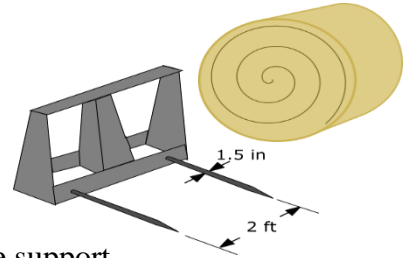
2. The windmill shown pumps water out of the ground at 150 gallons/hour when the wind speed is 20 mph. With these conditions, the windmill spins at 70 rpm experiences 101.5 lb-in of torque.
    a. What power does the windmill produce? (8pts)
    b. If the axle of the wheel is ¾ in. diameter solid steel shaft, what is the maximum shear stress? (14 pts)
    c. If the axle length experiencing this torque is 8 inches, what is the angle of twist of the axle when the wind is 20 mph? (14 pts)
    d. *What shear strain does the axle experience? (14 pts)
    e. *The axle connects to a 0.6 in. diameter shaft with a complete quarter circle fillet of 0.12 in, what is the maximum shear stress in the smaller shaft? (14 pts)
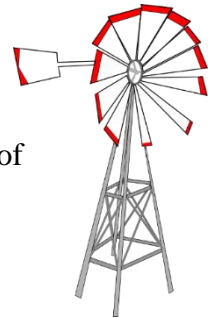
3. A platform (m_P = 5 kg) is suspended using <u>four</u> 16-gauge (d = 1.2903 mm) wires of A36 steel with nominal length of 1.5 meters. Normally, it is crossed by one dorset ewe (m_E = 80 kg) at a time, but while sorting sheep Farmer Bill (m_F = 84 kg) happens to step onto the platform with an older lamb with m_L = 52 kg.
    a. Under normal loading conditions (platform + ewe), what are ε_x and ε_y? Take the x-direction to be axial. (14 pts)
    b. When Farmer Bill and an older lamb step onto the platform, do the wires experience plastic deformation? Do the wires break? (14 pts)
    c. *If the wires behave as elastoplastic materials and have a maximum deformation of 3 mm, what permanent set is introduced? (14 pts)
    d. *If local temperatures range from -29°C to 41°C, how much do you expect the wires to change in length between the coldest and warmest days? (14 pts)
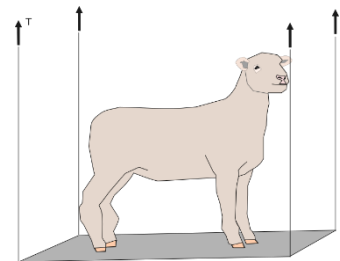
Appendix E: Home Alone Themed Exam: Rigid Body Kinetics and Kinematics

Engineering 2105 — Statics and Dynamics   Name: _____

Exam III —Ch.15-17

Closed Book & Notes — Centroid and Moment of Inertia Tables provided, one 8.5" x 11" equation sheet allowed (65 minutes)

You must clearly show your work to receive credit and make use of **Free Body Diagrams** wherever appropriate.

For the following problems use the following information:
*Unless otherwise noted, use standard axes, i.e. $+x \rightarrow$; $+y \uparrow$; $+z$ out of page*
Marv: $h_h = 1.800$ m; $m_h = 65$ kg; $I_h = 13.225$ kg m² (about an axis through G, $\widehat{k}$);
Harry: $h_m = 1.750$ m; $m_m = 75$ kg; $I_m = 14.237$ kg m² (about an axis through G, $\widehat{k}$);

1. In preparation for the burglars who have been lurking around the neighborhood, Kevin set up a tripwire across a hallway. When the wire trips Harry, $x_G = 0.100$ m. If $\vec{v}_G$ just before he hits the tripwire is $\{1.2\ \mathbf{i}\}$ m/s.

   a) Find the angular momentum of the burglar at this instant about the tripwire (Assume **ω** is still 0)

   b) When a vector from the tripwire to G has an angle of 45°, $\vec{v}_G = v_x\hat{\imath} + v_y\hat{\jmath}$ with magnitude 0.75 m/s. Using conservation of momentum, what is Harry's angular velocity at this time?

   c) When a vector from the tripwire to G has an angle of 45°, what is the velocity of point A on the top of Harry's head?
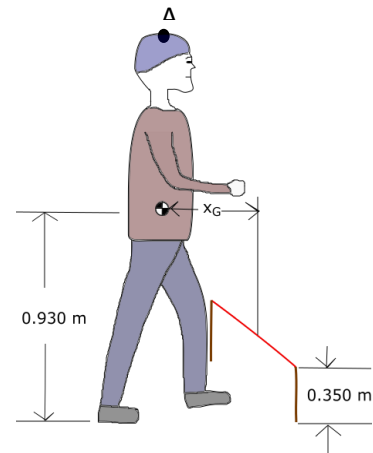
2. In the meantime, Marv is sneaking down a flight of stairs and steps on one of Kevin's strategically placed Micro Machines, giving his right foot a horizontal velocity of 1.5 m/s in the $\hat{\imath}$ direction, and an angular velocity of 2 rad/s $\widehat{k}$, and an angular acceleration of 1 rad/s² $\widehat{k}$.

   a) Where is Marv's instantaneous center of rotation (treat Marv as a rigid body with his right foot directly below G at this instant)?

   b) At this instant, what is the absolute velocity of Marv's CoM?

   c) What is his kinetic energy?
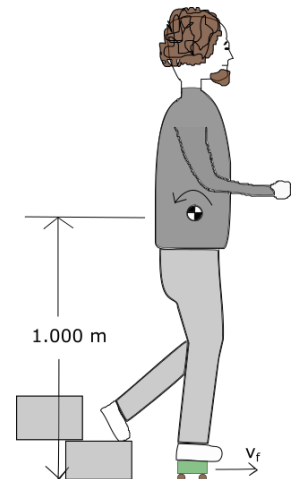
3. Once Marv has picked himself up off of the floor, he hears Kevin taunting him from the top of the stairs. He starts back up $\vec{v}_m = \{-0.7\,\hat{\imath} + 0.5\,\hat{\jmath}\}\,m/s$, only to be hit in the head by a paint can ($m = 2.00\,kg$) traveling at $\vec{v}_{pc} = \{3.5\,\hat{\imath} - 2.5\,\hat{\jmath}\}\,m/s$. The coefficient of restitution between the paint can and Marv's forehead is e = 0.5.

   a) Compute the cross product to prove the paint can and Marv have parallel velocities.

   b) Assume both pre-impact velocities are along the line of impact: $|v_m| = 0.8602\,\frac{m}{s}\,\nwarrow$; $|v_{pc}| = 4.3012\,\frac{m}{s}\,\searrow$. If Marv's head has a velocity after impact of **0.00** m/s, what is the velocity of the paint can?

   c) Using what you know about the paint can, what was the average force exerted between the paint can and Marv's head if the impact time was 0.20s?

1.000 m