AC 2008-1259: DEVELOPMENT OF KINESTHETIC-ACTIVE EXERCISES FOR A TRANSPORT PHENOMENA COURSE

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Development of Kinesthetic Active Exercises for a Transport Phenomena Course

Abstract

Teaching techniques that provide hands-on experiences could be useful in helping all learners, but especially kinesthetic learners, to understand conservation of mass, momentum, and energy. Helping kinesthetic learners is of particular interest in engineering since many engineering students are kinesthetic learners. The focus of this work is a required sophomore course that teaches fluid mechanics, thermodynamics, statics, and dynamics by using conservation of mass, momentum, and energy equations. It has proven to be a challenging course for students, particularly those who are kinesthetically inclined, as it requires solving a variety of physical problems starting from governing equations. In order to improve student learning, a set of kinesthetic active exercises was created to help kinesthetic learners by connecting physical understanding to theory via directed experimental experience.

Student volunteers completed both the Index of Learning Styles and the VARK test to evaluate their learning style predisposition. Five one-hour-long experimental sessions were designed to provide a group of 25 students with hands-on learning experiences related to the conservation concepts covered during course lectures. The experiments were chosen to clarify the relationship between physical phenomena and their mathematical representations. Generally, in these sessions, students were given a brief description of the operation of a hands-on experiment or exercise, asked to predict the outcome, and then asked to perform the experiment and comment on the results. Pre- and post-sessions tests were administered in selected sessions to evaluate the effects of the exercises.

Preliminary assessment of this ongoing project indicates that the hands-on sessions are helping students learn conservation principles, the foundation of engineering. Scores on post-session tests were significantly ($p < 0.05$, Wilcoxon signed ranks test) higher than scores on pre-tests. Students with a preference for kinesthetic learning (on the VARK test) showed a larger change in pre- to post-session test scores than non-kinesthetic learners. Students with grade point averages in the range of 2.51 – 3.00 showed a larger change in pre- to post-session test scores than students in other ranges of grade point average, and female students showed a larger improvement from pre- to post-session scores than male students. The present work describes the instructional approach used to develop kinesthetic active exercises for the sessions, presents assessment results, and describes changes planned for the next iteration of this experiment.

Introduction

Teaching techniques that provide hands-on experiences could be useful in helping all learners, but especially kinesthetic learners, to understand conservation of mass, momentum, and energy. Helping kinesthetic learners is of particular interest in engineering since many engineering students are kinesthetic learners. Active learning has been shown to increase student engagement and learning[1], and hands-on activities are a subset of active learning. Specifically, hands-on activities have been shown to be effective in helping students forge stronger links between physical concepts and theory[2,3,4].

The focus of the present work is a required sophomore course that teaches fluid mechanics, thermodynamics, statics, and dynamics by using conservation of mass, momentum, and energy equations. It has proven to be a challenging course for students, first because this is in many regards the first real engineering analysis course the students take, and second because although the conservation laws worked with in this class represent "the way the physical world works", this course is taught in a lecture-only format with extensive in-class active learning exercises, but no hands-on experiences. This is particularly challenging for those students who are kinesthetically inclined, as it requires solving a variety of physical problems starting from governing equations, all of which exist only on the board.

In order to improve student learning, a set of kinesthetic active exercises was created to help kinesthetic learners by connecting physical understanding to theory via directed experimental experience. Evaluation of the impact of the exercises on the student learning was assessed via statistical analyses.

Materials and Methods

Study Set-up and Assessment of Student Learning from the Sessions

All students who took the Fall 2007/08 offering of the ES 201 (Conservation and Accounting Principles) course were asked by e-mail to participate in a larger research project investigating the effect of supplemental learning opportunities (SLOs) and their match to student learning styles (described in detail in other work[5]). The present work focuses on the activities developed for the kinesthetic active experimental group (n = 25 students) of the larger study.

Students gave their informed consent to participate (IRB approval, RHS#0068), and student participation was voluntary and compensated. All students completed the Index of Learning Styles (ILS)[6,7] and the VARK questionnaire[8,9], and the supplemental learning opportunities (SLOs) described in this work were held on campus in a teaching laboratory on Tuesdays between 6:00 and 7:00 pm. Five one-hour kinesthetic active SLOs were held during the 10-week Fall 2007/08 quarter: the first two SLOs were held before the first exam in ES 201, the next two occurred between the first and second exam, and the final SLO occurred prior to the third exam in ES 201.

Assessments utilized in the kinesthetic active sessions were developed and scored by an instructor (who also teaches the ES 201 course) who met with the authors to discuss specific session learning objectives and general topics. The assessments were not seen by the authors prior to their administration during the kinesthetic active sessions.
Table 1 indicates the demographics of the students who participated in the kinesthetic active sessions, and table 2 provides the breakdown of these students into groups based on the degree of their preference for kinesthetic learning (based on the VARK, kinesthetic).

Table 1: Demographics of the student population who participated in the kinesthetic active SLOs

Number of students	25	**Percent female**	40%
		Primary majors:	
Grade point average:		Biomedical Engineering	6
Mean	2.93	Computer Engineering	2
Median	3.09	Electrical Engineering	6
Maximum	4.00	Engineering Physics	1
Minimum	2.08	Mechanical Engineering	10

Table 2: Scores on the VARK, Kinesthetic were used to establish groups with different kinesthetic preferences.

	Scores for degree of learning preference:		
	Least	*Moderate*	*Strongest*
VARK, Kinesthetic	2 or less	$2 \leq$ score ≤ 5	5 or more
Number of students	6	9	10

Development of the Hands-on Activities

The authors began the development of the activities for the kinesthetic active sessions by reviewing (individually) the performance of their students in previous offerings of the course, with particular attention paid to the occurrence of fundamental misconceptions. Special attention was given to student performance on ‘concept’ questions on the midterm exams (typically three in a quarter term) and the final, as these questions had been specifically developed to test core knowledge and could not be solved by ‘choosing the right equation’. After individually compiling lists of major errors that were made in the course of previous offerings, the authors met and discussed potential hands-on activities that might target these misconceptions. The intent was to make ‘Con Apps’ real to the student in the way it feels ‘real’ to the instructors.

This course is widely regarded as one of the ‘most challenging’ on campus, and each of the authors is a firm supporter of the addition of lab (or lab-like) activities to the course to enhance student learning. The authors come from fluids and solids backgrounds, respectively, and, as such, had complementary skill sets and expertise that proved useful during the development of the activities.

A major challenge faced in this course (based on the authors experience as instructors) is that a ‘dashed line’ on the board may seem adequate for the students to identify the system at hand (that is, the small piece of reality that is ‘set aside for analysis’), but for many of them, the system being analyzed remains merely a 'dashed line'. It's not a tank filling, with an inlet and an outlet. It's not a car accelerating. It's a dashed line. And, come on, who really cares about a dashed line? [Note: As reported by a student, "Dashed lines are those things you can drive across. Solid lines you cannot."]

The authors then grouped the particular challenges by topical area – conservation of mass, linear momentum, angular momentum, and energy – and set about placing these into the five sessions that were available. It was evident early on that there were a larger number of conservation of mass concerns than in the other areas, which initially seemed a bit odd. However, after discussing our rationale for identifying challenges, it was evident that since the course 'builds' on conservation laws starting from mass, it was important to ensure that students understood this conservation law so they could successfully (and confidently) move on to the others. It was also noted that historically, students have much more experience (for better or worse) with linear and angular momentum (for closed systems) from physics, so spending extra time on mass flows, open systems, and conservation of mass was warranted. The authors then met with the lead instructor for the ES 201 course (and also the author of the textbook) to solicit the opinion of someone who has taught this course from the beginning regarding student challenges. There were a couple of small changes in the observed challenges from this instructor, primarily in the emphasis on the challenge many students face in linking the equations to the physical situation. Specifically, many students could (for example) demonstrate the consequence of a system operating at steady state (a term goes to zero), but not be able to link the idea to the physical situation (extensive properties of the system not changing with time). From this meeting, several ideas for each topical area/concept were developed.

As the various activities were considered and developed, the overall 'test' of whether an activity was likely to be included was whether it would help the students make the connection between physical concepts and mathematical analysis abstractions. In other words, would the activity "take the material off of the board and put into their hands"?

Description of the Hands-on Activities

The hands-on activities that were undertaken during the five SLO sessions are described briefly here. A more detailed, step-by-step description of the activities and the additional student actions/work in the sessions is provided for the interested reader in the Appendix.

The first kinesthetic active session explored conservation of mass principles. Things were started with an ethanol/water demonstration that illustrated the importance of conserving mass and not volume. An instructor mixed equal volumes of water and ethanol and revealed to the (surprised) class that resulting volume was less than the combined original volumes. Next, a 10 cc syringe (without needle) was given to each group and they were asked to try to compress a volume of air and then to compress a volume of water to illustrate the difference between compressible and incompressible substances. The students were also asked to pull a volume of water into the syringe and see that none of the water would exit without pushing the plunger as no mass could flow in. A toilet mounted on a moving dolly to create a "toilet on wheels" was brought in, and students tried to predict the various tanks and connections in the toilet prior to working with it directly (and flushing it into an oil pan). Subsequently, students revised their system representations for the toilet and worked to duplicate (and test) the physical structure using a set of water "tinkertoys" created for the session.

The second session also focuses on conservation of mass principles, with an emphasis on steady state systems and species accounting. A sink mounted onto a moving dolly (yes, a "sink on wheels") was used to illustrate the design of steady state into a device as a safety precaution, as well as the concept of a 'mixing tee' in a household element. During the next session, a steady state system was illustrated by a three tank system, with each tank at a different height and connected by hoses. The water was transported from the lowest tank to the highest by a high flow rate aquarium pump and flowed into an intermediate tank before ultimately flowing to the collection tank. A valve on the intermediate tank allowed students to control the flow to the collection tank in order to achieve steady-state operation. Finally, species accounting was demonstrated by giving students components of a salsa recipe and having them compute the components after weighing the combination.

The third session explored impulsive forces and conservation of linear momentum. It began with students exploring surface friction and impulsive forces by pulling a placemat from under a bowl, thereby performing the classic 'pull the tablecloth out from under the place setting' trick. This time is was the 'placemat magic trick', but it did provide insight into impulsive frictional forces. They then used Newton's cradle to explore conservation of linear momentum. Next, an air filled balloon attached to - and held aloft by - a vertically oriented fan was used to illustrate transport of linear momentum with mass flow. Students then measured the effects of different padding materials on reduction of peak impulsive forces generated by dropping a weight into a bucket (with the padding placed at the bottom of the bucket). Finally, a brick sliding on an accelerating skateboard illustrated sliding friction and acceleration.

The fourth session explored conservation of angular momentum and began by showing tipping of a tumbler due to the placemat being pulled from beneath it. A length of 1" diameter PVC tubing with attached handles demonstrated moment couples and application of moments. For the next two activities, student used the skateboard from session three to illustrate tipping of objects due to both external forces (contacting a tube standing on the skateboard as it passed under a bar) and applied accelerations (the skateboard being accelerated producing tipping of tube).

The fifth and final session involved conservation of energy related activities. Students were given a hairdryer and measured both the velocity and temperature of its output flow and compared it to the energy input via electricity. A Nerf™ dart gun was aimed vertically and used to illustrate conversion of spring potential energy to kinetic energy and then to gravitational potential energy. To make the potential energy increase of the Nerf™ darts more easily measurable, it was necessary to increase their weight, so a standard six-sided die was attached to the suction cup on the dart.

Table 3 summarizes the complete set of kinesthetic active exercise developed and utilized through the five SLO sessions in the present work.

Table 3: Summary of the kinesthetic active exercises undertaken in the present work, by session.

	Activity:	***Concept:***
Session 1	Ethanol/Water demo "Toilet on Wheels" Water "tinkertoys"	Conservation of Mass Mass flows Mass flows
Session 2	"Sink on Wheels" Multiple tank system Salsa	Mass flows Steady state systems Species accounting
Session 3	Placemat "magic trick" Balloon/Fan Impulsive bucket (w/padding) Brick and skateboard	Impulsive forces Momentum transfer w/mass flow Peak impulsive forces Friction (sliding) and acceleration
Session 4	Placemat "magic trick" II Moment tubing Tipping due to contact Tipping due to acceleration	Tipping due to impulsive forces "Feeling the moment" Angular momentum at a point Tipping not just a contact issue
Session 5	Hair dryer Nerf™ dart gun	Conversion of energy forms Spring energy -> kinetic -> potential

Results and Discussion

Impact of the Kinesthetic Hands-on Activities

In general, student scores in the active and sensing domains of the ILS and the kinesthetic domain of the VARK were not correlated; the largest and only statistically significant correlation was between the kinesthetic and sensing domain scores (Spearman's rho = 0.30, $p < 0.05$, n = 25). These data indicate the various domains in the instruments appear to assess different aspects of information processing.

The pre- and post-session assessments conducted for the third SLO (focused on conservation of linear momentum, impulses, and friction) will be provided as the preliminary assessment of the series of five kinesthetic active SLOs. Table 4 shows the performance of students on the pre- and post-session assessments broken down by the strength of their preference for kinesthetic learning.

Table 4. Performance on the pre- and post-sessions assessments, sorted by K-VARK, and overall.
* indicates significant (Wilcoxon Signed Ranks test, $p < 0.01$)

	Assessment		
	Pre-3	*Post-3*	*Change*
Strongest Kinesthetic Learners (n=10)	2.80	3.80	1.00
Moderate Kinesthetic Learners (n=9)	3.44	3.67	0.22
Least Kinesthetic Learners (n=6)	4.33	5.00	0.67
Overall (n=25)	3.40	4.04*	0.64

Students with the least strong preferences for kinesthetic learning scored higher on both the pre- and post-session assessments, but students with strong preferences for kinesthetic learning scored made the largest gains in score between pre- and post-session assessment. There were no significant differences observed for the groupings by strength of preference for kinesthetic learning, so the data were pooled and a statistically significant increase in score from pre- to post-session assessments was observed (Wilcoxon Signed Ranks test, $p < 0.01$).

The assessment utilized for this pre- and post-session evaluation consisted of both questions testing concepts and questions asking students to draw appropriate free body diagrams. Since much of the intent of the kinesthetic active sessions was to 'make real' otherwise abstract concepts using real examples, scores on the concept portion of the assessment and the free body diagram portion of the assessment for the overall group were separated out and analyzed. It was found that there were no significant changes in the student scores from pre- to post-session assessment questions that focused on drawing free body diagrams, but that there were statistically significant increases in student performance from pre- to post-session assessment on questions testing concepts. It would appear that the overall increase in performance from pre- to post-session assessment was therefore largely driven by increases in student understanding of core concepts.

Further analysis was conducted to determine if there was any effect of student GPA on performance on the pre-session assessment, the post-session assessment, as well as on the change between individual student scores from pre- to post-session assessments. GPAs were binned by range (3.51 – 4.00, 3.01 – 3.50, 2.51 – 3.0, 2.01 – 2.50), and it was found that there was a significant effect of GPA on the scores on the pre-session, scores on the post-session, and changes in score from pre- to post-session (Kruskal-Wallis Test for multiple comparisons, $p < 0.05$). Students with GPAs in the range of 2.51 – 3.00 showed the largest gains between pre- and post-session assessments than students in other ranges of GPA. Female students had lower scores on both pre- and post-session assessments, but also showed larger gains from pre- to post-session assessment than male students.

While the results of the present work are interesting, it would be unwise to generalize these findings since they come from a single assessment pairing and with relatively small numbers. However, the effects of even a relatively short set of kinesthetic interventions are encouraging and warrant further analysis and study.

Reception of the Kinesthetic Hands-on Activities

Overall, the kinesthetic hands-on activities were generally well received by students across all five of the supplemental sessions, with students willing to continue 'playing along' week to week. Moreover, students seemed to enjoy the activities – with most group responses to the activities (with some exceptions) ranging from mild to substantial enthusiasm, based on the level of noise and overall activity in the room. More importantly, and as noted above, the kinesthetic hands-on activities appear to help all learners (from strong kinesthetic to least kinesthetic preferences) improve their performance on a pre- and post-session assessment (for Session 3). This was particularly true of the 'concept' aspects of the assessment, and given the lecture-only format of the course, it makes sense that any supplemental hands-on activities that made course material "more real" would only benefit the students.

While the instructors worked to develop all activities to be engaging, "real world", and to utilize concepts that the students interact with in their daily lives, a few of the activities stand out as particularly compelling for the student groups. The syringe, the "toilet on wheels", the multi-tank system, the impulse bucket, and the dart gun were resounding successes for student engagement (based on instructor perception). The hair dryer, although it brought together a range of energy concepts into one very real package, and the "sink on wheels", as much a part of everyday life as the toilet, both felt as though they were notably less compelling for the students. The instructors have been working to determine if there is a common thread in the activities that might explain why certain hands-on activities are more engaging than other, and have initiated a study to address this (for use in the development of future activities)[10].

Improvements for the Next Iteration of Kinesthetic Hands-on Activities

At the conclusion of each kinesthetic hands-on session, both instructors made individual notes on the apparent success (or failure) of the various activities. Some weeks after the conclusion of the final session of supplemental learning opportunities, the instructors met to discuss potential changes and ideas for future activities.

One area of identified need (at the time the hands-on activities were implemented) was that of a viable mass flow-momentum hands-on experiment. The balloon/fan set-up was initially developed such that the students would construct airfoils from cardboard and vary the fan speed to maintain the airfoil in the air stream. However, even with tethering from the center of the airfoil to the center of the fan (using a length of fishing line and a fishing spinner), preliminary testing revealed that challenges in the 'symmetry' of the airfoil led to instability of the airfoil in the air stream (and then out of the air stream). So, a change was made to the more stable, yet somewhat less engaging tethered balloon in the air stream of a vertically-oriented fan.

It is with some irony that the authors report that during clean-up for this experiment (Session 3), the release of a balloon from its attachment site on the fan led to quite an unexpected surprise. Detaching the fishing spinner from the fan – which left an air-filled balloon, a length of fishing line of approximately three feet, and the fishing spinner connected as a grouping – led almost immediately to the balloon attaining a dynamic, yet stable, position in the air stream approximately six feet above the fan. Similar detachment of the other fishing spinners led to similar dynamically stable positions of other balloons in their respective air streams above their respective fans.

One specific change that will be made will be to the dart gun activity from Session 5; while this engaged the students well in the activity, a direct and more hands-on improvement should probably include the students physically disassembling the dart gun. As noted in the detailed description of the hands-on activities (by Session) in the Appendix, these toy guns were extremely inexpensive, and yet were assembled almost entirely with screws . . . a surprise in this day and age.

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Appendix – Detailed Description of the Hands-on Activities (by Session)

The following detailed description of each of the hands-on activities is provided by session, and also in the order within the session the activity was utilized. Specific notes as to what students were directed to do are included to provide greater context for the various experiences the students had.

Session 1 – Ethanol/Water, Syringe, "Toilet on wheels", Water "tinkertoys"

The first session focused on conservation of mass and mass flows, and began with a demonstration of the importance to make the distinction between conservation of mass and the often-invoked concept of 'conservation of volume'. An instructor mixed equal volumes of ethanol and water and demonstrated that the resulting volume was notably less than the combined original volumes. The compressibility of air and water were then examined using a 10 cc syringe (without needle). Students were directed to pull the plunger back to draw air into the barrel of the syringe, the to block the tip of the syringe with a finger, and to attempt to depress the plunger. Using the fill markings on the barrel of the syringe, students were asked to estimate how much they were able to compress the air inside the syringe using reasonable force on the plunger. Subsequently, students expelled the air from the syringe and drew only water into the syringe and repeated the same process. In general, students were stunned by the fact there was effectively no compressibility to the water. (Note: The instructors, though they did not say this at the time, were a little stunned by the students' surprise/astonishment at the behavior of the liquid under compression.) Students were then asked to draw half water, half air into the barrel, and repeat the process of compression. In this last example, compression of the combined mixture was possible, although to a lesser degree than the air only, and students were then asked to speculate on the source of the observed compressibility.

A standard, household toilet, mounted on a moving dolly to create a "toilet on wheels" was unveiled at the beginning of the session. Students were then asked to draw a system representation for the various tanks and mass flows involved in the flushing of a toilet, and to discuss these in their groups. Student groups were then given the opportunity to examine the toilet closely in hands-on fashion (it was a new toilet), and the toilet was fully plumbed (drawing water from an adaptor from a lab faucet) and therefore could be flushed into a large oil pan beneath the toilet while students watched the various tank drainings and fillings. Students were then asked to re-draw/modify their system representation for the toilet based on their observations, and then to duplicate their system representation using some water "tinkertoys" constructed for the exercise and provided to each group. These water "tinkertoys" were an assortment of valves, tubing, nozzles, funnels, and small reservoirs, and each group was given more elements than they needed to: 1) ensure that the a wider variety of system representations could be accommodated (not all system representations were correct, even after observation), and 2) further ensure that there was not a single obvious set of connections to be made. Once the groups had their physical analogue constructed they then tested it with water.

Session 2 – "Sink on wheels", Multiple tank system, Salsa

This session explored more conservation of mass concepts, including steady state systems, as well as species accounting. To begin the session, a second household tank system was brought in – this time a standard bathroom sink (and cabinet) mounted on a dolly to make a corresponding "sink on wheels" – and student groups were directed to speculate on the various mass flows into and out of the sink. After coming to consensus on a system arrangement, student groups were given the opportunity (one team at a time) to examine the sink and watch its function; the sink was also plumbed, and drained into a five-gallon bucket inside the cabinet. At this time, care was taken to ensure that every team observed that there was (by code) an 'overflow' drain mounted on the sink to handle the eventuality that the main drain should be blocked (or flow-limited) while the faucets were running). Teams tested the 'safety' of the overflow drain in taking the system to steady state by actively trying to overflow the sink, finding that the system did achieve steady state some 5 mm below the sink rim (it was a rather inexpensive sink, admittedly). Groups then modified/updated their system representations, and the 'mixing' feature of the faucet itself was discussed by the instructors, and the fact that they use them personally every day in the shower. When previously asked if they could name a mixing tee in their house/apartment/dorm, the vast majority of the students could not, except by referring to 'some plumbing in the walls'.

Student groups were then asked to work with a three-tank water system, with each tank at different heights (floor, table, and one intermediate) and connected by hoses. Water was transported from the lower tank (main reservoir) to the highest tank by a high flow rate aquarium pump and flowed into the intermediate tank before returning to the lowest tank. The highest tank had a siphon installed which drained directly back to the lowest tank which activate if the water level got too high. A valve on the exit of the highest tank enabled students to control the flow rate into the intermediate tank, and served as the only 'control' point in the system (other than slight adjustment on the aquarium pump flow rate). Students were asked to run the system and attempt to adjust the system to reach steady-state operation. Species accounting was then explored by student groups working with a salsa recipe and providing them with components of the recipe, but not enough information to determine the %, etc. of unknown components without species accounting and a scale. [Note: Real chips and salsa were provided outside the lab (in the hall) after the conclusion of the species accounting exercise since it seemed inappropriate to work with food that could not be eaten, and also to reinforce lab safety regulations.]

Session 3 – Placemat 'magic trick', Balloon/Fan, Impulsive bucket (w/padding), Brick and skateboard

This session moved on to impulsive forces and conservation of linear momentum. A standard placement and bowl (serving as a simplified place setting) was provided to each group, and the instructors demonstrated the classic 'pull the tablecloth from under the place setting' trick using the placemat and bowl. Prior to the groups performing the magic trick, they drew a system diagram for the bowl during the placemat pull. Once the students had drawn their system diagrams, they were given the opportunity to perform their own magic trick. After all students had successfully done some 'magic', they were asked if any forces other than gravity were acting on the bowl, which led them to overall agreement that there was kinetic friction acting on the bowl as the placemat was pulled out from under it. Groups were then asked to explain why the bowl did not fall off the table as the placemat was pulled, and to further come up with an explanation grounded in linear momentum. Each group was then given a 'Newton's Cradle' to experiment with conservation of linear momentum, and an air-filled balloon attached to – and held aloft by – a vertically-oriented fan was used to illustrate the transport of linear momentum with mass flows.

Students were then given the chance to explore the effects of different cushioning materials on the peak impulsive forces arising from a weight being dropped into a bucket. A wooden beam clamped to a table provided the support, and a five gallon bucket (with the cushioning placed inside) was connected to the support through a spring-based fish scale (range: 0 – 50 lbf) was used to 'catch' (and ideally also contain/constrain) the dropped weight. A sliding ring on the fish scale enabled students to determine the peak impulsive force reached for each trial. Finally, student groups accelerated a skateboard by pulling on a rope attached to a brick placed on the skateboard, to examine the changes in the frictional interaction between the brick and skateboard associated with the changing boundary conditions on the skateboard wheels (blocked vs. limited vs. free-rolling).

Session 4 – Placemat 'magic trick' II, Moment tubing, Tipping due to contact, Tipping due to acceleration

This session examined the conservation of angular momentum, and began by returning to the placemat 'magic trick', but this time with the addition of additional aspect to the place setting: a tall plastic tumbler. Prior to any attempts to pull the placemat out from under the place setting, student groups were again asked to diagram the system for the tumbler as the placemat was pulled out (to be contrasted with the previous bowl system). They were also asked to predict the behavior of the tumbler during the placemat pull, and every group predicted that unlike the bowl, the tumbler would tip over. Potentials reasons for this were explored within the groups, and the specific differences in geometry and mass (and the location of the center of mass of the tumbler) were identified as the culprits. To make physical the concept of a moment, a section of one-inch diameter PVC pipe was used, with similar diameter PVC 'handles' mounted transversely at two locations (nearer the center of mass, and farther away from the center of mass). Groups tested the moment required 'by hand' to maintain the PVC pipe in a horizontal position for each of the handle sets, and determined which was greater. They were then asked to diagram both situations, and to verify that their physical observation could also be obtained from conservation of linear momentum. When asked to come up with an example that might be similar to holding the handle set closer to the center of mass – where the mass of the remaining PVC pipe farther away from the center of mass is contributing to holding the pipe horizontal – students reported that the 'train crossing arm' was the most common example (at least locally).

The skateboard from session 3 was used again to explore the tipping of objects due to both physical contact and due to acceleration. Using a section of tubing (3 inches in diameter and approximately 8 inches in height) placed vertically on the skateboard on a table, the skateboard was rolled towards a 'limbo stick'-style horizontal obstruction (a thin dowel). By varying the height of the horizontal obstruction, the students induced forward tipping over the dowel, backward tipping under the dowel, and backwards sliding of the tube on the skateboard. These represented forces applied to the tubing below, above, and right at the level of the center of mass of the tubing, respectively. To examine tipping due to acceleration, the configuration was changed by the groups. The skateboard was again placed on the table with the tubing on it, and a line was attached to the front mount of the skateboard and passed over a pulley to a bucket hanging over the side of the table. Weight placed in the bucket was used to accelerate the skateboard once it was released from rest. To minimize the potential for uncontrolled skateboard movement, as well as the bucket and weights striking the ground, the skateboard was tethered through the back mounts via a long bungee cord to the wall. This bungee cord was long enough to enable the skateboard to accelerate, but stopped the skateboard before it reached the table edge. Dried pinto beans were used as the weight in the bucket to enable teams to determine (to within plus or minus a few beans, using a scale) the weight that would just produce tipping of the tubing backwards as the skateboard began accelerating from rest. Groups then worked from this experimental measurement and a system composed of the skateboard, the tubing, and the bucket/beans to determine the acceleration that would just produce tipping of the tubing.

Session 5 – Hair dryer, Nerf™ dart gun

The final hands-on session involved activities to illustrate conservation of energy topics. The session began with student groups developing a system diagram for a typical household hair dryer (with hi-lo settings and a cool air feature). After they had completed this task some discussion was undertaken specifically to make clear that depending on the system they selected for analysis, there might be no heat transfer. That is, a system containing the hair dryer and everything inside would take in energy, and increase the speed of the air and increase it temperature, but all heat transfers would be 'inside' of the system. Teams then utilized instant read, metal-tipped cooking thermometers to determine the temperature of the air entering and exiting the hair dryer on different settings, as well as flow meters to assess inlet and outlet velocities. These values were used to estimate energy consumption, which was then compared to the energy provide to the hair dryer (with known voltage and an inductive current meter placed around one of the power supply lines). The students considered a what-if scenario; what if the hair dryer was accidentally laid down on a counter and the air intake was blocked? From direct experience, they all knew that the hair dryer would get hot, and they then checked the way that conservation of energy could show that with no airflow, the incoming energy was being used to heat the trapped air as well as the internal components of the hair dryer. Students then examined an 'exploded view' hair dryer to see the internal workings, and also to see the thermal switch present in the barrel, placed there just to address such an potential problem.

The second exercise of this session involved a toy dart gun (Nerf™), which was used to examine conversions of energy between various forms. Student groups were given the dart guns and used force gauges to determine the force required to cock the gun, and in that way determine the energy stored in the spring. Given the mass of the dart, and assuming no energy losses in firing, students then predicted the speed of the dart upon exiting the gun, and the height the dart would travel if launched vertically. Prior to testing the dart gun, students were asked to predict the internal structure of the dart gun, meaning, "How is the potential energy of the spring converted into kinetic energy of the dart?". Students were then able to examine a dart gun that had been dismantled earlier by the instructors and placed on a board, opened in book fashion. Note: Given the cost of the dart gun (very inexpensive) the instructors were quire surprised (yet thrilled) to find that it was held together by a total of 17 screws, and could therefore be non-destructively taken apart. Students and instructors alike marveled at the engineering involved in the dart gun, and then students tested the vertical height of the dart travel. To make the potential energy of the darts easier (and, in fact, possible) for the students to measure, a single six-sided die was attached to the suction cup tip of the dart. [Note: If you haven't fired a toy dart gun in a while, you're in for a surprise . . . both in the performance of the dart guns, and also in the variety and number of dart guns (and dart gun playing systems) available at the toy store. Be forewarned however, these aren't your father's dart guns, or even the ones you grew up with.]