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ABSTRACT

Undergraduate and graduate students in courses designed to introduce research techniques in exercise physiology were provided the novel opportunity through project-based learning (PjBL) to utilize a prototype device to measure energy expenditure (EE). This report summarizes how EE measurements were incorporated via PjBL into course-required experiments and determined perceived understanding of exercise and metabolism. Undergraduate experiments included measurement of EE following high intensity cycling preceded by a motivating yell, and EE after upper-body and lower-body exercise performed at simulated altitude. Graduate experiments included evaluation of the EE cost of skipping, and EE during longboard skateboarding. Undergraduate students perceived greater increases in competencies while graduate students seized the opportunity to design more creative experiments that pushed the boundaries of their education.

Keywords: exercise metabolism, choice-based learning, collaborative education

Teaching Applied Exercise Physiology Using a Prototype Energy Expenditure Measurement Device

The earliest recorded examples of exercise-related benefits come from China (employing breathing exercises, 1050-256 B.C.E.) and India (disease prevention including physical exercise, circa 600 B.C.E.) (Tipton, 2008, 2014). Greek physicians (Hippocrates, 460-370 B.C.E) and philosophers (Aristotle, 384-322 B.C.E) continued to expound the advantages of exercise and its relationship to health (Hale, 2008; Ivy, 2007). Advancing forward in time, the term physiology was introduced by Jean Francoise Fernel (1497-1558) (Hale, 2008), one of the first Physical Education departments in the US was created in 1854 at Amherst College, and Harvard University offered the first exercise physiology course in 1892 (Ivy, 2007). By 1922, A.V. Hill and Otto Meyerhof were awarded the Nobel Prize for Physiology or Medicine for their work on muscle metabolism (Bassett, 2002). With this storied history, exercise physiology courses have become an essential offering in the area of kinesiology, and the study of metabolism is a central pedagogical tenet (Ivy, 2007).

Metabolism is broadly defined as the sum of the biochemical processes within the body. When framed in an exercise perspective, textbooks include topics such as topics macromolecules utilized as energy substrates, energy-producing pathways, and how this energy is utilized by working muscle (Kenny et al., 2020). From a research perspective, topics are varied and there are several well-written systematic reviews on basal metabolic rate (Compher et al., 2006; Frankenfield et al., 2005), submaximal (Ferrar et al., 2014; Smith et al.,

2016) and maximal oxygen consumption (Bacon et al., 2013; Montero et al., 2015), and substrate utilization (Braun & Horton, 2001; Weinheimer et al., 2010). Thus, students in exercise physiology have a wide variety of topics to explore when considering the area of exercise and metabolism.

Problem-based learning (PBL) and project-based learning (PjBL) have similar pedagogical elements (e.g., active learning, authentic tasks, and student collaboration (Bos & Lee, 2010; Savery, 2006). In PBL, the problem is focused on the use of reasoning strategies, and the teacher serves in the capacity of a tutor. In contrast, the problem in PjBL focuses on the scientific inquiry process, and the teacher functions in the role of a coach (Bos & Lee, 2010; Savery, 2006). Several characteristics of PjBL have been identified including a learner-centered approach, collaboration, and learning that is valued in the real world (Savery, 2006). Compared with traditional teaching practices (e.g.,, lectures), PjBL shows improved learning outcomes, places students at the center of learning activities, and encourages the application of acquired scientific knowledge (Cifrian et al., 2020). Teachers' perspectives of PjBL in science-based curricula were that the approach increased group interaction, led to greater research proficiency, and improved communication (Turgut, 2008). Other benefits include engaging reluctant learners (Jones et al., 1997), increasing interest in topics (Bartscher, 1995), and utilizing projects that are realistic and authentic to real-life situations (Thomas, 2000).

The Department of Kinesiology and Nutrition Sciences at the University of Nevada, Las Vegas offers a variety of courses touching on the subjects of exercise physiology and exercise metabolism. Two courses (undergraduate-level Applied Exercise Physiology, and graduate-level Evaluation of Physical Work Capacity) are experiential in nature and designed with a PjBL approach to introduce students to various research techniques in exercise physiology. Students spend the first portion designing a mini-experiment and the second portion executing their experiments. Students in these courses were recently provided the novel opportunity through PjBL to utilize a prototype device to measure energy expenditure (EE) when conducting their mini-experiments. The two goals of this report are to (1) summarize the various ways that undergraduate and graduate students incorporated EE measurements into their experiments and (2) determine the extent to which they perceived an increase in their understanding of exercise and metabolism.

Description of Practice

Two critical components of PjBL include (1) a dynamic question or problem and (2) an artifact as the end product as a representation of learning that has taken place (Grant, 2011). The key problem was how to incorporate access to a desktop energy expenditure device into the mini-experiments for exercise physiology-based courses. The energy expenditure device was a novel opportunity provided to students enrolled in the courses, as it represented prototype equipment unavailable to the general public. Two artifacts that mimic real-world scientific outputs were required at the end of the experience. The first artifact consisted of both a poster presentation and an oral presentation disseminated in the form of a simulated scientific conference. The second artifact was a scientific journal-style manuscript.

An application was submitted to the institutional review board (application #1525298), and it was determined that the protocol could be excluded as it did not meet the definition of human subjects' research. The EE measurement device (hereafter referred to as Apollo EE) was provided by Sable Systems International (North Las Vegas, NV). The Apollo EE is a desktop device that is paired with a respirometry mask, a hood, or a metabolic tent to measure human metabolic rates. Because we were measuring EE during exercise, we chose to use masks for all experiments described hereafter. These masks have unique features. During inhalation, they allow fresh air to enter through two valve openings on each side of the mask. During exhalation, the breath is pulled from the center of the mask into a high-flow air stream (e.g., 80-200 liters per minute; LPM) that is constantly being directed into the Apollo EE (see Figure 1). Although air is continually drawn from the mask, the Apollo EE device automatically switches (at 15-second intervals) between measuring oxygen levels in ambient air and the air stream exiting the mask. The differences in the fractional oxygen levels between incurrent and excurrent gas samples permits the calculation of fractional depletions ($\Delta FO2$) in oxygen that are needed for EE measurement.

Figure 1. Illustration of air flow through Apollo EE mask.

The Apollo EE calculates EE in real-time via an open-flow dilution technique that is independent of carbon dioxide measurement (or measurement of respiratory exchange ratios) using an equation originally proposed by Weir (1949). This equation was more recently validated by Kaiyala et al. (2019) who determined that EE (kcal/min) = 5 · ΔFO2· FR, where FR refers to flow rate (in LPM). The Apollo EE differs only with respect to the output units calculating EE (kcal/day) = 7200 ·ΔFO2· FR.

The pedagogical aim of both the undergraduate and the graduate courses is to give students the chance to design a novel experiment, make measurements, analyze data, and synthesize their conclusions in a manner in-line with current scientific practices. This type of hands-on educational opportunity is highly beneficial to the students to prepare them to design and implement their own independent studies further in their careers (Trnova & Trna, 2011). In this sense, the role of the instructor was to facilitate learning through introduction of the problem, encourage idea development, and provide feedback and consultation. Students in the undergraduate course were all seniors in their last year of the program (Kinesiology). The learning outcomes included the following skills:

- complete a scientific literature search on topics related to exercise physiology;
- demonstrate competence in select exercise science laboratory techniques;
- successfully compose laboratory reports with the following sections: introduction, methods, results, discussion;
- critically evaluate and peer review laboratory reports and scientific literature; and
- design and carry out a project which demonstrates an ability to apply knowledge in exercise physiology.

Students in the graduate course were first year masters (MS Kinesiology) or first year doctoral students (Interdisciplinary Health Sciences). The learning outcomes included the following skills:

- demonstrate competence laboratory techniques including
  - o flexibility,
  - o muscular strength and endurance,
  - o aerobic capacity,
  - o anaerobic capacity,
  - o body composition;
- design and carry out a project which demonstrates an ability to apply knowledge in exercise physiology; and
- compose a manuscript with the following sections: introduction, methods, results, discussion.

As the structure of the course has been described previously (Navalta et al., 2012), this section will briefly describe the development of ideas and concepts leading to the mini-experiment. The process develops over the course of the semester, with students initially considering several options during active-learning/brainstorming sessions. The projects are gradually refined as students search available literature and group/team discussions are held regarding feasibility. Students then develop a data collection plan and write a mock institutional review board application that is submitted to the instructor. The plan is then implemented, revised when necessary, and students collect data during the time allotted to class instruction. Students then analyze the data obtained, apply appropriate statistical testing, draw conclusions, and generate a mock abstract as though they were submitting to a scientific conference.

The culmination of the experience is a three-pronged final assessment composed of the following components: (1) poster presentation, (2) oral/podium presentation, and (3) manuscript-style write-up. The poster and oral components are presented at a mock conference where students obtain experience with these methods of dissemination in a low-risk environment. Students receive constructive feedback on their mini-experiments and can incorporate changes into their final documents, which are turned in as a mock manuscript submission during finals week. To gauge student experience after final grades were posted, students completed an online questionnaire (see Figure 2). The questions centered around a combination of learning outcomes stated in the syllabi and items suggested by the manufacturer of the novel Apollo EE desktop device.

Interpretation

After several brainstorming sessions, potential undergraduate projects were proposed: determining the metabolic cost during active video gaming; measuring metabolism during a peak power test; observing post oxygen consumption following a bout of exercise using the VersaClimber (Heart Rate Inc., Santa Ana, CA) while under simulated altitude; determining EE at different rates of jumping rope; and validating EE of wearable technology under differing exercise bouts. Due to time constraints, the undergraduate class agreed upon the following two projects to conduct and carry out in a collaborative effort.

Figure 2. Questions on student perceptions in utilizing the prototype desktop energy machine in undergraduate and graduate exercise physiology courses. The survey was created and administered using Qualtrics (Provo, UT) software.

Undergraduate Project #1 Title: Energy Expenditure During a 6-second Peak Power Test while Yelling

Purpose

Previous research has been completed to determine ways of increasing power output without the use of ergogenic aids, and the use of vocal cues is common. One investigation utilized a pre-repetition "kiap" by martial artists and found that greater power output was generated when compared to a no kiap control condition (Welch & Tschampl, 2012). By increasing the power output during an exercise, a logical assumption is that EE is also increased. As such, the students hypothesized that performing a free-choice psych-up technique would increase the EE by increasing the power output during a six-second peak power bike test.

Methods

Peak power was calculated using a Wattbike Pro (Wattbike, Nottingham, UK) and the Wattbike Pro Hub application. After being fitted with a mask and the Apollo EE, the seat height of the bike was adjusted to fit the participant. Individual pedaling resistance was calculated for each participant as a percentage of their body weight. The participant was given a five-second countdown to prepare prior to the five-second ramp up, which was audibly counted down. The goal was to reach peak power within the first two seconds of the six-second peak pedaling. Participants then cycled as fast as they were able for six seconds to generate their greatest power output or the peak power. Participants were asked to yell or grunt during the ramp upstage. Half of the participants were asked to complete a yell prior to the six seconds of peak power on the first data collection day, while the second half was asked to yell on the second data collection day. On the days when no yell was incorporated, participants completed the exercise silently. Upon completing the cycle phase, participants engaged in 54 seconds of active recovery followed by four minutes of passive recovery. Post-exercise EE was measured during this time for a total of five min, 20% active and 80% passive.

Undergraduate Project #2 Title: Energy Expenditure Between Upper Body and Lower Body and Their Relationship to Their Respective Mass

Purpose

Excess post-exercise oxygen consumption (EPOC) is the amount of oxygen the body consumes following strenuous activity that is above and beyond the pre-exercise oxygen consumption baseline (Gaesser & Brooks, 1984). Exercise is known to produce an increase in oxygen consumption in the resting post-exercise state. As the rate of oxygen consumption remains elevated, the increased metabolism cost continues to be a factor in the thermic effect of activity, and EPOC can be affected by a number of factors, including intensity of the activity, exercise duration, and modality (Navalta et al., 2018). As exercise intensity increases, both the magnitude and duration of EPOC increases. When comparing upper-body and lower-body EPOC responses, findings indicate no significant differences when exercises were performed at a comparable relative metabolic intensity between upper-body exercises (arm crank) and lower-body exercises (cycle ergometer) (Sedlock, 1991). The students hypothesized that there is a direct relationship between EE of lower limbs and skeletal muscle mass of lower limbs, as well as a relationship between EE of upper limbs and skeletal muscle mass of upper limbs. They also hypothesized that EPOC magnitude values of EE of the lower body (legs) would be higher when compared to those of the upper body (arms). Therefore, the purpose of the study was to determine whether there was a relationship amongst lower and upper limbs and their respective skeletal mass, and to determine if there were any major differences among EPOC EE magnitude values between upper body and lower body.

Methods

For body composition analysis, a bioimpedance analyzer was used (SECA GmbH 514 Company, Hamburg, Germany). Skeletal muscle mass was calculated using the following two equations: upper-body muscle mass = left upper extremity segment + right upper extremity segment; lower-body muscle mass = left lower extremity segment + right lower extremity segment. The Sports Rehab Model (VersaClimber, Heart Rate, Inc., Santa Ana, CA) was used for the simulated climbing exercise with an altitude training system (Hypoxico Everest Summit 11, New York, NY) setting level at 10.5 = 12,750 feet or 3,886 meters. This study was performed over the course of two days, and half of the participants completed the upper-body exercise on day one, and the other half completed lower-body exercise on day one. The conditions were reversed for day two, with the participants completing the condition they had not yet completed on the second day. For three minutes, the participants performed one session of the upper-body exercise while seated and one session of the lower-body exercise without the seat. The metronome was set to 80 beats per min. The participants began climbing (stepping) using the lower extremities with the arms placed on the handlebars or push-pull motion of the upper extremities while seated, in time with the metronome. At the end of the three minutes, the metronome was stopped, and the participant quickly removed themselves from the machine and immediately secured the Apollo mask for five minutes of recovery time while seated.

Several brainstorming sessions were also employed by graduate students. Results of these sessions yielded potential graduate projects that included EE while exercising and employing differing breathing techniques, the energy cost of skipping, energy expended while fielding softball ground balls, and the energetics of longboard skateboarding. Due to time constraints of the semester, the graduate class agreed upon the following two projects to conduct and carry out in collaboration.

Graduate Project #1 Title: A Comparison of Caloric Expenditure During Walking and Skipping

Purpose

Walking is the primary method by which humans maneuver through their environments on a daily basis. Though the invention of bicycles, scooters, and motorized vehicles offer alternative means of transportation, walking remains an accessible and often-used form of locomotion for much of the human population. Most humans naturally develop the ability to transition from walking to running as a faster method of travel. While efficient in terms of the rate of travel, running does require a greater EE than walking (Harrell et al., 2005). Anecdotally, it has been observed that certain individuals, particularly children, enjoy skipping as a middle-ground movement and alternative to walking or running. However, it is unknown whether the energy cost of skipping for locomotion has been formally evaluated. Rope skipping is somewhat comparable to skipping: it involves a concentric contraction of the lower-body musculature to generate a downward force into the ground, a flight phase with both feet off of the ground, and an eccentric contraction of the lower-body musculature as the body contacts the ground and absorbs the landing force. However, skipping for transportation also involves forward propulsion that is absent in rope skipping. This factor is an important consideration, given that muscle forces which create forward propulsion may be responsible for half of the energy cost of walking (Gottschall & Kram, 2005). In light of the ambiguity surrounding the energy cost of skipping for travel in normal gravity, researchers conducted the present exploratory study with a primary two-fold purpose: to determine if EE differs between walking and skipping and, if so, to identify the magnitude of difference. Therefore, the hypothesis stated that five minutes of walking at a self-selected pace would elicit a different EE compared to five minutes of skipping at the same speed.

Methods

Participants completed two sessions, separated by seven days. All participants were asked to fast for at least three hours (h) prior to data collection. Upon entering the room for Session One, participants self-reported their body height and mass they had obtained from recent objective measurements using a stadiometer and balance-beam scale. Thereafter, participants completed a self-selected dynamic warm-up before initiating a protocol to determine their respective self-selected walking speeds. To identify these speeds, participants initiated a walk from standstill on a treadmill (Precor C956; Precor USA, Woodinville, WA) set at a 1% grade. Participants were blinded to the treadmill speedometer using a piece of paper taped over the treadmill screen. Participants began walking, altering the speed, and verbally reported when they had reached a comfortable walking speed. Researchers then stopped the treadmill, recorded the speed, and replicated the procedure twice, for a total of three speed self-selection trials. Researchers finally calculated the arithmetic mean of the three trials, with the quotient serving as the walking and skipping speed for the subsequent session. The mean speed for all participants was 3.0 ± 0.5 mph.

During Session Two, each participant completed the walking and skipping trials (always walking before skipping), separated by a rest period lasting approximately 45 minutes. Skipping was defined as a gait pattern involving a “double-tap” (two separate occurrences of contact) of the trailing foot and a flight phase for each movement cycle. All walking and skipping trials lasted five minutes. Participants’ ventilation rates were measured using the Apollo EE. The loss of data points during the first two minutes of data collection for several participants necessitated the evaluation of only the last three minutes of each trial for all participants. Nevertheless, this procedure allowed the students to compare statistically the differences in EE between walking and skipping.

Graduate Project #2 Title: Metabolic Costs of Longboarding on a Treadmill: A Pilot Study

Purpose

Longboarding is a common method of transportation by students on college campuses. Longboards are similar to skateboards but have a longer board, bigger wheels, and a generally smoother ride. To date, the energy expenditure (EE) of longboarding or skateboarding has been examined twice (Board & Browning, 2014; Hetzler et al., 2011). Board and Browning (2014) asked riders to longboard at slow, moderate (normal), and fast paces while wearing a portable metabolic system that measured oxygen consumption and carbon dioxide production. Their study found that the average EE of longboarding was 7.93, 10.01, and 12.64 kilocalories [kcal]/min at slow (13.32 km/h), moderate (16.2 km/h), and fast speeds (18.36 km/h), respectively (Board & Browning, 2014). When measuring the metabolic cost of skateboarding, Hetzler et al. (2011) found that skateboarding at a speed of 17.06 km/h resulted in a total energy cost of 10.3 kcal/min. In both experiments, the EE of the participants were measured in a field test where the participants could actively kick to propel themselves forward.

The EE breakdown of longboarding can further be resolved if baseline EE of only riding (rather than both propelling and riding) is known. Therefore, the purpose of the present study was to measure the EE of longboarding while balancing on the longboard, without the addition of any type of propulsion. (Propulsion involves kicking the ground and swinging the arms to move the longboard forward.) The students hypothesized that longboarding at a faster pace would produce the greatest metabolic cost because this action should require the most effort to maintain balance and keep the board centered on the treadmill.

Methods

Participants attended a single data-collection session at the exercise physiology teaching laboratory. An Axis 40 longboard (Arbor Snowboards, Inc., Venice, CA) was used and strapped to a treadmill, allowing only horizontal (left and right) movement on the treadmill belt. The longboard was anchored to the front of the treadmill with a rope, preventing any vertical movement (front to back) along the treadmill belt. The standing platforms of the treadmill acted as bumpers so that the longboard could not roll off the side of the treadmill. The Apollo EE was utilized to determine EE during the trials. Prior to data collection, a familiarization trial of one minute was completed. This trial involved gradually increasing the speed of the treadmill belt until the participants felt comfortable riding on the board. During data collection, participants longboarded on the treadmill for 10 consecutive minutes under three conditions: standing on the longboard at 0 km/h, riding at 4.0 km/h, and riding at 8.1 km/h. The speed was changed every 3.3 minutes, and the sequence of treatments was randomized a priori.

Perceptions of using the EE device

Perceived change in student ability based on access to the Apollo EE is shown in Table 1. In general, undergraduate students perceived a larger change in abilities than graduate students, with the largest increase occurring in confidence and ability in carrying out physiological data collection. The greatest perceived change for graduate students occurred in confidence and ability in writing an institutional review board application.

Next Steps

Undergraduate and graduate students were given a unique opportunity to utilize a prototype EE measurement device through PjBL to design and execute experiments in exercise physiology in their respective courses. This paper described the approach employed by students, potential projects, and the final iteration of the mini-experiments. One notable limitation is that the questionnaire that was utilized to gauge student perception was not a validated instrument; however, students successfully utilized the Apollo EE in the completion of the project. All students felt the opportunity

Question	**Undergraduate Mean±SD**	**Graduate Mean±SD**
Critical thinking about physiological processes	73±32	37±9
Confidence/ability in reading and understanding associated literature	69±25	40±30
Confidence/ability in designing physiological investigations	77±19	48±18
Confidence/ability in writing an institutional review board application	76±18	68±14
Confidence/ability in carrying out physiological data collection	98±4	45±29
Confidence/ability in analyzing data	80±17	55±23
Confidence/ability in drawing conclusions around physiological concepts	77±20	40±22
Confidence/ability in writing a scientific report	67±20	64±10

Table 1. Undergraduate and graduate perceived changes due to PjBL and access to the Apollo EE during applied exercise physiology courses. These values represent self-reported changes in percent competence between the beginning and end of the semester.

enhanced the learning environment, and undergraduate students perceived a greater change in understanding of exercise and metabolism.

While the main objective was not to compare the undergraduate and graduate experience, differences in perceived scores should be noted. As graduate students already had some experience with the research process, it is not surprising that change scores were lower for every item, as it is likely that these students entered the course with an increased amount of competence and confidence in their abilities. These participating graduate students were also a nonhomogeneous group of master's level and doctoral students. On the other hand, undergraduate students had very few opportunities for involvement in the research process prior to enrolling in this course. These observations are in line with the research on undergraduate versus graduate students (Frymier et al., 1996; Yazici, 2005) and novice versus expert practitioners (Burger et al., 2010; Daley, 1999).

Undergraduate students are motivated to a greater extent when empowered to make choices in the classroom (Frymier et al., 1996). Choice-based learning approaches result in a moderate increase in undergraduate motivation for mastering the material (Lewis & Hayward, 2003). When considering a collaborative learning approach, undergraduate business students tended to seek guidance, structure and control in mastering course materials (Yazici, 2005). Undergraduate students who enrolled in the Applied Exercise Physiology course described in this paper were exposed to a mix of collaborative learning in laboratory teams. These students were also empowered to make choices regarding their final mini-experiment hypotheses and methodology. The greater potential for change, relative to graduate students in combination with the employed learning approaches, possibly led to the largely perceived increases in capacity. Given this finding, researchers noted the undergraduate students adhered more closely to structure when designing the mini-experiments incorporating the Apollo EE, as both were extensions of previous literature (Navalta et al., 2018; Welch & Tschampl, 2012).

Graduate students more closely resemble the expert learners that have been described in the literature. When considering a collaborative learning approach from a graduate student perspective, business students tend to be more independent learners who are more confident in their abilities and willing to take more initiative (Yazici, 2005). With respect to the nursing learning environment, expert learners tended to use more informal mechanisms compared to novices in constructing a knowledge base for themselves (Daley, 1999). Another study on nurses in the field found that beginners prioritized tasks in a linear manner while experts took a holistic approach to patient care (Burger et al., 2010). A parallel was observed with graduate exercise physiology students in the present report, as they seemed more willing than undergraduates to push the boundaries on their PjBL mini-experiment concept and design. The approach included creativity in projects that students would not normally have an opportunity to pursue during their graduate education.

A fundamental understanding of exercise physiology is paramount within the broader field of kinesiology (Ivy, 2007). Because exercise is as important today as it was in ancient times (Tipton, 2008, 2014), students within this field must develop an understanding of a broad range of topics in exercise physiology, including the subfield of exercise metabolism. Undergraduate and graduate students had the unique opportunity to utilize the Apollo EE in their applied exercise physiology courses via PjBL. All students perceived that access to this device increased their understanding of physiological processes and gave them greater confidence. Overall, the undergraduate students perceived greater increases in competencies while graduate students seized the opportunity to design more diverse mini-experiments that pushed the boundaries of their education.

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Dustin Davis is a doctoral candidate in the Interdisciplinary Health Sciences program at the University of Nevada, Las Vegas (UNLV). Before UNLV, he earned a BS in Physical Education and MS in Kinesiology with a focus in exercise physiology at the University of Central Missouri. At UNLV, Dustin collaborates with his faculty advisor, Dr. James Navalta, to study how people perceive outdoor exercise in green (grassy and/or forested) and brown (desert) environments. The aspects of perception that Dustin focuses on are mindfulness and the love for and care of nature. Beyond research, Dustin teaches anatomy and physiology labs and exercise physiology lectures. He enjoys running, reading for fun, and procrastinating by doing both. More than anything else, Dustin cares deeply about bonding with his family, friends, and colleagues. For him, he never feels more connected to others than when he is making them smile and laugh. He will do just about anything to make that happen. Dustin is still waiting to hear Dr. Navalta play the banjo, which definitely counts for something.

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