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An Investigation of How Students Use Information to Answer Energy Questions

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Abstract

This study investigated how students used information provided in given energy questions while answering these questions. Participant students were taking at least one college-level introductory science course and were asked to respond to two-tiered format (multiple-choice question and short written response question) energy questions addressing different scientific situations. Students' written responses were analyzed using text analysis techniques to extract terms and phrases. The terms and phrases were then subjected to analysis to identify key ideas aligned with students' choices in the multiple-choice components. The study revealed that students who focused on surface-level features of the given questions failed to answer correctly, while students who used the underlying energy concepts were more likely to answer successfully. The findings from this study can inform teachers and researchers about students' difficulties in understanding of energy concepts and applying energy concept to a certain situation.

Introduction

Energy is a core, unifying concept across all science disciplines and grade levels. Although energy is one of the most central and richly connected ideas in science, students often have a great deal of difficulty understanding it (Driver, Squires, Rushworth, & Wood-Robinson, 1994). A variety of studies have investigated students' understanding of the energy concept and their prior conceptions of energy that they bring to science class. For example, Liu and McKeough (2005) utilized five aspects of energy, 1) energy associated with activity/work, 2) energy source/form, 3) energy transfer/transformation, 4) energy degradation, and 5) energy conservation, to testify a hierarchical order in understanding of the energy aspects, and found that the hierarchy existed in student understanding of the energy aspects. Park and Liu (2016) and Lee and Liu (2010) also found that the understanding of energy conservation was more difficult than identifying energy sources or recognizing energy transfer for students.

Although there have been many studies of students' conceptions in energy, most focus on identifying students' typical or common conceptions while overlooking evidence on why students have not made scientifically correct decisions. Insights into the reasons for students' failure to understand scientific concepts could be useful for developing new curricular as well as teaching strategies. Studies of student learning in science have used various methods to reveal students' learning difficulties, misconceptions, or learning progressions, including interviews and/or open-ended questionnaires (Novak, 1987; Mitchell & Gunstone, 1984; Osborne & Gilbert, 1980; Watts, 1985). Although interviews are effective to investigate students' thinking and diagnose their misconceptions in science, a large amount of time is required to train interviewers and interview students (Chen, Lin, & Lin, 2002). Using two-tiered test items was suggested to overcome those difficulties and diagnose possible misconceptions held by students (Treagust, 1985). A two-tiered item is composed of a multiple-choice question as the first tier and an open-ended question as the second tier of each item.

Although using two-tiered items is effective for diagnosing students' conceptions, analyzing students' written responses results by hand coding requires tremendous time and effort. In order to overcome these barriers to using written response questions, many researchers are using technologies such as computerized text analysis or machine learning (Haudek et al., 2011; Nehm & Haertig, 2012). This method allows researchers to identify the key ideas used by students to answer the questions. Further, key ideas can be used to identify how those ideas are correlated in students' responses, which has the potential to provide evidence for why students fail or succeed in producing scientifically correct responses. This method not only helps identify students' conceptions, it also provides information regarding their difficulties or lack of knowledge, which may be useful for developing new teaching materials and teaching strategies.

The purpose of this study is to explore what information provided in a given question students use to solve the question, and how the information is related to scientifically correct answers. Specific research questions guiding the study were: 1) What information provided in given questions do students use to answer the energy questions? 2) To what extent is the information used by students different between scientifically correct and incorrect answers?

Knowledge Integration

In answering questions, Chi, Feltovich, and Graser (1981) found that experts used scientific principles or laws that were applicable to a given problem, along with a rationale for why those laws applied to the problem. On the other hand, novices answered questions by memorizing, recalling, and manipulating equations. Chi, Glaser and Rees (1982) also noted that novices focused on surface features of a given problem, while experts connected ideas from the question with the scientific laws and the conditions under which laws were applicable.

One reason for novices' fragmented knowledge is that traditional instruction typically presents ideas that are isolated rather than integrated for students (Linn, 2006). Linn (2006) suggests four interrelated processes that jointly lead to integrated understanding through knowledge integration processes: 1) students elicit current ideas, 2) add new, normative ideas, 3) develop criteria to evaluate ideas, and 4) sort out their ideas and build strong connections among ideas. Based on the four interrelated processes, Lee and Liu (2010) defined the knowledge integration construct as students' knowledge and ability to elicit and connect scientifically normative and relevant ideas in explaining a scientific phenomenon or justifying their claim in a scientific problem.

The SOLO (Structure of the Observed Learning Outcome) taxonomy is also related to measuring the knowledge complexity in students' learning outcomes, focusing on the number of cues and interrelations among those cues to analyze student responses. More specifically, Biggs and Collis (1982) developed the SOLO taxonomy, consisting of five levels in a learning progression that represents five different ways in which students respond to assessment tasks. These levels are "Prestructural," "Unistructural," "Multistructural," "Relational," and "Extended abstract." In the case of a prestructural response, students demonstrate no logical interrelation between ideas. In the case of a unistructural response, students can generalize only based on one aspect of a concept. For a multistructural response, students can generalize based on a few limited and independent aspects without integrating those independent aspects. In the case of a relational response, students can generalize within given or experienced contexts using related aspects by induction. The relational response gives an overall concept or principle that accounts for the various isolated data, but does not involve generating a new knowledge nor using other information beyond what is a given in the question. The extended abstract response involves logical deduction going beyond induction, which implies that students can generalize to situations not experienced. This level response is equivalent to experts' responses (Chi, Feltovich, & Graser, 1981; Chi, Glaser, & Rees, 1982).

Method

Instrument and Participants

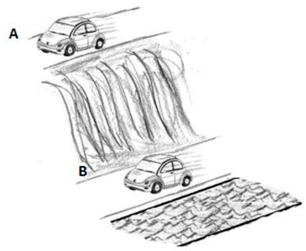
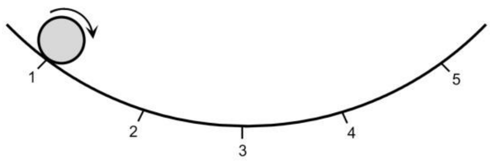
The Inter-Disciplinary Energy Assessment (IDEA) (Park & Liu, 2016) instrument was designed to investigate students' understanding of the energy concept. The IDEA instrument consists of four test forms, physics, chemistry, biology, and environmental science. In this study, two questions in the physics test form of the IDEA were selected, which both addressed the same content topic of mechanical energy (i.e., potential energy and kinetic energy).

The first question was originally developed by Neumann et al. (2013), and the second question was developed originally by AAAS. Park and Liu (2016) extensively modified the two questions to assess students' understanding of different energy aspects; energy form and energy conservation within the content topic, i.e., mechanical energy, and included in their instrument (IDEA). Specifically, one question addresses a height difference between two identical moving objects to assess students' understanding of energy form (i.e., potential energy and kinetic energy), and the other question addresses energy transformation and conservation while an object is rolling on a curved track (i.e., energy transformation between potential energy and kinetic energy).

Participants were recruited from college level science classes at four colleges in Pennsylvania, New York, and Washington in the U.S. When collecting data, participants were taking at least one introductory level science course (e.g., physics, chemistry, biology, and environmental science). Science courses for both science majors and nonscience majors were included to obtain from a wide range of student abilities. Participants have not taken any advanced college science courses previously.

The questions and the number of participant students are presented in Table 1.

Table 1. Energy questions

Question	N[a]
1. Two identical cars (Car A & Car B) are being driven with same speed but on two different roads above a river as shown below.  What can you tell about the energy of these cars? A. Car A possesses more energy than Car B. B. Car B possesses only kinetic energy and Car A possesses only potential energy. C. Both cars possess the same amount and types of energy. D. Car A possesses less energy than Car B. ***Explain your choice**	183
2. A ball, starting from rest at Position 1, rolls back and forth along a curved track and eventually stops rolling, and the ball gets a little warmer.  How does the total energy of the ball and track system change as the ball rolls along the track? (Note: Assume no air friction) A. Increases B. Increases first then decreases C. Decreases D. Decreases first and then increases E. Remains the same ***Explain your choice**	173

Note. aN indicates the number of participants

Analysis Method

Students' responses were subjected to analysis using IBM SPSS Modeler (v.18.0) with Text Analytics (TA) software. The Software extracted terms and phrases from text data, and grouped them into categories such that each category represented a homogenous concept. Categories can be created or revised using linguistic algorithms contained in the software or defined by the researcher.

The software then classified each student response into one or more categories based on the terms and phrases used in their responses. After finalizing categories, students' chosen multiple choice options were subjected to discriminant analysis along with the categories to identify important attributes contributing to students' multiple choice answers. To perform discriminant analysis, the author used the categories as independent variables and students' chosen multiple choice options as the dependent variable.

Results

Category Development

Using extracted words and phrases from students' written responses to two energy questions, 29 categories were developed. In this process, the author ensured that each category contained only scientifically homogeneous terms (Table 2).

Table 2. Terms and categories

Category Name	Terms
Comparing Quantity/Faster	faster, speed increased
Comparing Quantity/Less	less, decrease, loss
Comparing Quantity/more	more, increase, greater, gain
Comparing Quantity/same	same, identical, constant
Energy	energy, overall energy
Energy Form/Kinetic Energy	kinetic energy, $1/2mv^2$
Energy Form/Potential Energy	potential energy, gravitational potential energy
Energy Form/Thermal Energy	thermal energy
Energy Principle	dissipate, energy can't be created or destroyed, energy can't be created, energy is constant, low of conservation, never used up
Energy Transfer/Transformation	transform, transfer, release, displace energy, switch
Force/Force and Accel(eration)	force, acceleration, propel
Force/Friction	air resistance, friction, frictional force
Force/Gravity	gravity, gravitational pull
Mass	mass, weight
Misconception of Energy	runs out, builds energy, create energy, consume energy
Movement/Falling Down	free fall, fall
Movement/Motion	motion, move, travel, drive, running, vibration, roll
Movement/Speed	velocity, speed
No Effect	no effect, not effect, not affect, not change
Physical Feature/Height	water fall, steeper incline, slope, altitude, elevation, higher
Physical Feature/momentum	momentum
Product/Heat	heat, warm
Status/Lower State	lower energy state
Status/Stability	equilibrium, settle, rest
Stop	stop
Surface Feature/Flat Road	straight stretch road, flat road, flat platform, flat ground
Surface Feature/Object	object, ball, ramp
Surface Feature/River	water running, water, sea, river
Surrounding	surrounding, atmosphere

Question 1 Analysis Results

Question 1 was designed to assess student understanding of energy forms. The question addresses a situation in which two identical cars were moving on roads of which the heights were different from a river. Among 183 students, 36.1% (n = 66) students chose the option "A. Car A possesses more energy than Car B" and 54.6% (n=100) students chose the option "C. Both cars possess the same amount and types of energy". The other options were selected by few students; 2.2% (n=4) students selected the option "B. Car B possesses only kinetic energy and Car A possesses only potential energy" and 7.1% (n= 13) students chose the option "D. Car A possesses less energy than Car B."

As a result of the text analysis of students' written responses, 10 categories out of 29 emerged from more than 10% of the responses. Using the 10 categories, discriminant analysis was performed to determine if there were differences in the emergent conceptual categories between students' answer choices to the multiple choice component. Note that two options, B and D, were excluded from this analysis since few students chose them. Consequently, the responses of students who chose either A or C in the multiple choice component were analyzed.

Figure 1 shows the comparisons of category frequencies between the two groups of responses; Option A responses vs Option C responses. For example, almost 85% of option A responses mentioned potential energy (category name: *Energy Form/Potential Energy*), while only around 5% of option C responses stated potential energy.

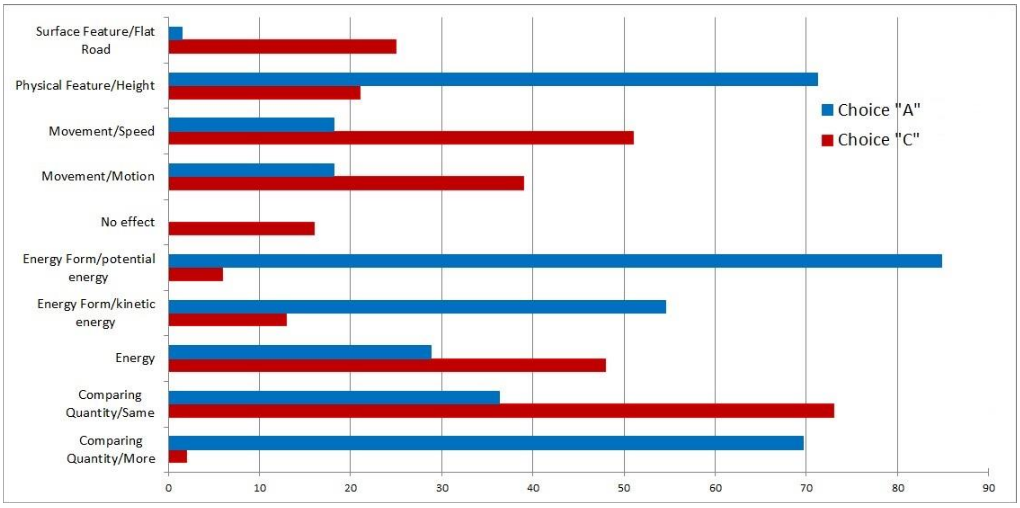


Figure 1. Category percentage comparisons of question 1

Discriminant analysis analyzes the covariance among independent variables to determine an optimal combination of independent variables discriminating between groups (i.e., dependent variables). In this study, 10 categories were used as independent variables and student choices to the multiple choice component were used as a dependent variable. The discriminant function showed good classification accuracy (Wilks' Lambda = 0.217, chi-square = 242.625, df =10, p < 0.0001). The group centroids (the mean values for the discriminant scores) for the two groups were 2.321 for option A and -1.532 for option C. Table 3 shows the standardized canonical discriminant function coefficients (similar to beta weights in a regression analysis) for each of the categories on the discriminant function and the discriminant structure coefficients which are simple correlations between scores on a particular variable and the discriminant score (Spicer, 2005).

Table 3. Discriminant coefficients and structure coefficients for each category in question 1

Category Name	Standardized Coefficient	Structure Coefficient
Energy Form/Potential Energy	0.553*	.697
Comparing Quantity/More	0.488*	.564
Comparing Quantity/Same	-0.436*	-.206
No Effect	-0.362*	-.145
Physical Feature/Height	0.336*	.304
Energy Form/Kinetic Energy	0.251*	.262
Movement/Motion	-.132	-.119
Surface Feature/Flat Road	-.125	-.176
Movement/Speed	-.045	-.185
Energy	-.005	-.103

Note. * indicates key variables from the forward stepwise method.

The three largest positive coefficients are 1) *Energy Form/Potential Energy,* 2) *Comparing Quantity/More*, and 3) *Physical Feature/Height*, indicating that students selecting option A used these ideas significantly more than the other group of students in their answers. The two largest negative coefficients are 1) *Comparing Quantity/Same* and 2) *No Effect*, indicating that students selecting choice "C" often used these ideas in their explanations. The stepwise discriminant analysis also selected those five categories as key variables to distinguish between the two groups of responses.

When using the 10 categories as independent variables and the two multiple choice options as dependent variables in a stepwise discriminant analysis, the model explains 77.62% of the variance in the grouping variable, i.e., whether a respondent chose A or C. The discriminant function correctly classified 92.8% of the cases in a jackknife, leave-one-out resampling (see Table 4).

Table 4. Number of cross-validated student responses for question 1 classified at each multiple choice option

		Predicted Response		Total
		A	C	
Actual	A	61	5	66
Response	C	4	96	100

Figures 2 and 3 present web diagrams showing how students used the ideas (categories) together in their responses (Haudek et al., 2011). Figure 2 is a web diagram for responses of students who chose option A, and figure 3 is for responses of students who chose option C. In the web diagrams, categories are represented by nodes, and lines connecting nodes represent the responses that contain both those categories. The node size represents the number of responses placed in that category. Therefore, smaller nodes represent less frequent ideas in the responses. Lines between nodes represent the proportion of responses that contain both of the categories. The percentages of shared responses were calculated using the number of responses in the smaller node. For example, in figure 2, a solid line connects *Physical Feature/Height* and *Energy Form/Potential Energy,* indicating more than 75% of students' responses stated a road height (*Physical feature/Height*) also contained the idea potential energy (*Energy Form/Potential Energy*). If fewer than 25% of responses in the smaller node were shared with other categories, no line representing that connection was included.

Figure 2 shows that many students noticed a physical difference between the two cars' locations; *Physical Feature/Height*, and connected the difference to different energy forms; *Energy Form/Kinetic Energy* and *Energy Form/Potential Energy*. Not only did students connected potential energy to a height difference, but they also associated potential energy to an amount difference for the energy form; *Comparing Quantity/More*.

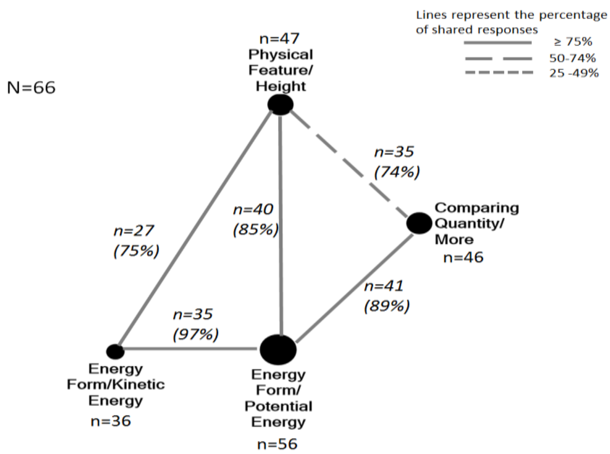


Figure 2. Web diagram for responses of students who chose the option A

Here are some example responses reflecting the model shown above.

> *Student1:* I think car A has more energy because even though they appear to be moving at the same speed (same kinetic energy) car A has more potential for falling over the water fall (so it has a higher potential energy).

Student 2: Since Car A is higher the potential energy for car A is higher. Even though their kinetic energies are the same, potential energies are not.

Student 3: In both A and B the exact same cars are moving at the same speed so their Kinetics Energies would be equal. However, it appears that Car A is Higher above the river and would have more potential energy because of this.

As seen in the example responses, student 1, 2, and 3 noticed the height difference between Car A and Car B (node: Physical Feature/Height), and mentioned both types of energy, i.e., potential energy and kinetic energy, (nodes: Energy form/Kinetic Energy and Energy form/Potential Energy). They also compared the amount of potential energy between two cars and said that the amount of potential energy is more or higher for Car A (node: Comparing Quantity/more, link: between Energy form/Potential Energy and Comparing Quantity/more).

Next, figure 3 illustrated that students who selected option C were more likely to focus on the two cars' motion and on the fact that both roads were flat; *Surface Feature/Flat Road* and *Movement/Motion*. These features might influence students to believe that there was no effect on the cars in terms of energy because those features were identical; *Comparing Quantity/Same* or *No Effect*. In the web diagram, categories including specific energy forms did not appear, which indicates less than 10% of students' responses contained the categories. This result implies that students who chose choice C focused mainly on the visible or surface level information provided in the question rather than using the energy concept.

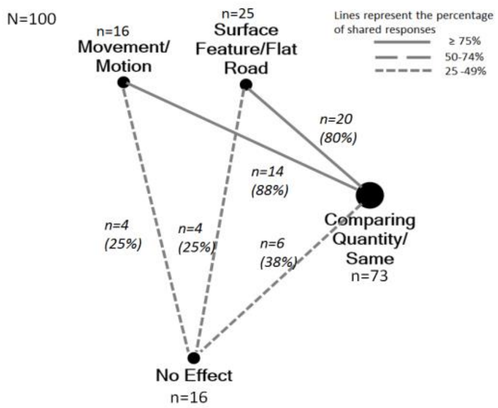


Figure 3. Web diagram for responses of students who chose the option C

Students' responses reflecting the model were presented below.

Student 4: Because both cars are moving at the same rate of speed which makes them the same.

Student 5: They are both moving at the same speed, therefore they have the same amount of energy.

Student 6: They have the same speed both driving of flat road. Flat ground will not have an effect on their energy.

In examples above, student 4, 5, and 6 didn't mention specific types of energy. Their responses showed that they used the information directly provided from the question, which was two cars are moving at the same speed (nodes: Movement/Motion and Comparing Quantity/Same, link: between Movement/Motion and Comparing Quantity/Same). Student 6 also mentioned flat roads on which two cars are driving (node: Surface Feature/Flat road) and said that it won't influence on the amount of energy of two cars (node: No Effect, link: between Surface Feature/Flat road and No Effect).

Question 2 Analysis Results

Question 2 was designed to assess student understanding of energy transformation and conservation. 16 categories out of 29 appeared in more than 10% of student responses. Among 173 respondents, 43.9% (n=76) students chose the option "B. Increase first then decreases" and 32.9% (n=57) students chose the option "E.

Remains the same", while 4.6% (n=8) students chose the option "A. Increases", 15.0% (n=26) students chose the option "C. Decreases", and 3.5% (n=6) students chose the option "D. Decreases first and then increases." In the analysis, the most popular options, B and E, were selected to compare students' ideas revealed in their written responses.

Figure 4 presents category percentage comparisons between the responses of the two groups of students' whose choice was either option B or E.

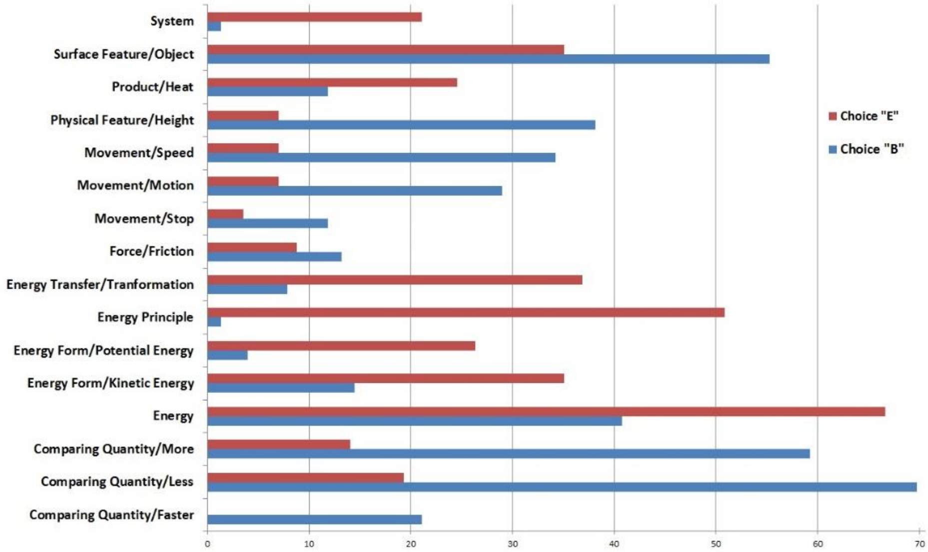


Figure 4. Category percentage comparisons of Question 2

Using the two groups (Students who chose option E and students who chose option B) as a dependent variable and the 16 categories as independent variables in a discriminant analysis, the resulting function showed good classification accuracy (Wilks' Lambda = 0.290, chi-square = 152.314, df =16, $p < 0.0001$). The group centroids were -1.794 for the option E response group and 1.345 for the option B response group.

Table 5. Discriminant Coefficients and structure coefficients for each category in question 2

Category name	Standardized Coefficient	Structure Coefficient
Energy Principle	-.464*	-.463
Energy Form/Potential Energy	-.440*	-.218
System	-.400*	-.223
Comparing Quantity/More	.353*	.328
Physical Feature/Height	.352*	.244
Comparing Quantity/Faster	.339*	.216
Surface Feature/Object	.336*	.131
Energy	-.310*	-.169
Comparing Quantity/Less	.304*	.368
Product/Heat	-.212*	-.108
Energy Form/Kinetic Energy	-.182	-.159
Movement/Stop	.132	.097
Movement/Speed	.102	.217
Movement/motion	.098	.182
Force/Friction	.056	.044
Energy Transfer/Transformation	-.041	-.244

Note. * indicates key variables from the forward stepwise method.

Table 5 shows the standardized canonical discriminant function coefficients and structure coefficients for each category. The result indicated that using the *Energy Principle* was the most important attribute to choose the option E. It also revealed that students who chose option E were more likely to include the categories, *Energy form/Potential energy, Energy, Product/Heat* and *System* along with *Energy Principle*, which were not provided directly in the question, but required students to infer the information associated with the given situation. Whereas, students who chose the option B tended to use the information directly provided from the question such as the track and/or ball's shape (*Surface Feature/Object*, *Physical Feature/Height*) and the ball's movement (*Comparing Quantity/More, Faster, or Less*). In summary, this result indicates that the two sets of variables, "Energy, Potential energy, Energy Principle, Heat, and System" and "Object, Height, More, Faster and Less" were critical to move an individual case toward option E or B centroids. The stepwise discriminant analysis also selected the same categories as key discriminant variables between the two groups.

As a result of the stepwise discriminant analysis, the canonical correlation for this question was 0.834, suggesting the analysis model explains 69.6% of the variation in the grouping variable. The discriminant function correctly classified 89.5% of the cases in a jackknife, leave-one-out resampling (see Table 6).

Table 6. Number of cross-validated student responses for Question 2 classified at each multiple choice option

		Predicted response		Total
		B	E	
Actual response	B	73	3	76
	E	8	49	57

Figure 5 and 6 present web diagrams illustrating students' ideas; Figure 5 is for students who chose option E, and figure 6 is for students who chose option B. Specifically, figure 5 illustrated that students who chose option E (the total amount of energy remains the same) used the *energy principle* (i.e., the conservation of energy) to explain their reasoning. However, it was noticeable that the *energy principle* and *energy transfer/transformation* category appeared together only in nine students' responses, which indicates that many students used the energy principle without explanation on how energy was transformed in the system.

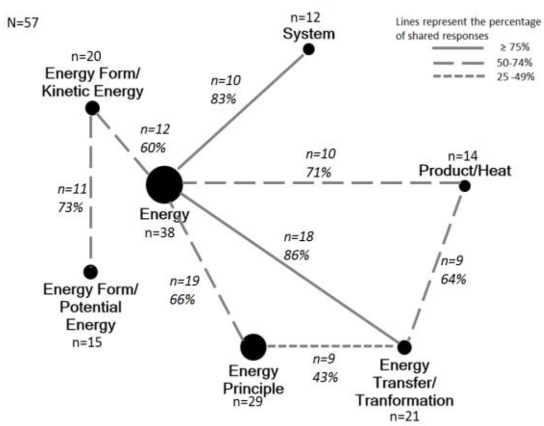


Figure 5. Web diagram for responses of students who chose the option E

Here are some example student responses.

> *Student A:* The total energy of a system never changes. It can only transfer or transform into different energy.
>
> *Student B:* The P. E. is converted into K.E. of the ball and the heat energy. But the total amount is conserved.
>
> *Student C:* Since we are looking at the total energy of the SYSTEM including the ball and track, no energy is lost (the total energy of a system remains constant).

In the above examples, student A, B, and C mentioned that the total amount of energy in the system is conserved, which indicated that they utilized the conservation of energy (node: Energy Principle) in answering the question. Further, student A and B said that energy can be transformed into different energy forms (node: Energy transfer/Transformation), but still the total amount of energy is conserved (link: Energy transfer/Transformation and Energy Principle). Especially, student C emphasized that they need to consider the total amount of energy of the system, which demonstrated that the student used the idea of energy principle in the system (node: Energy Principle and System, link: between Energy Principle and System).

Contrarily, students who selected the option B used the information of the ball's and the track's physical properties more often; *Surface Feature/Object*, *Physical Feature/Height* and *Movement/Speed*, and focused on comparing their quantity changes rather than considering energy aspects; *Compare Quantity/Faster, Less,* and *More* (see Figure 6). This result indicates that many respondents, but not all, had a lack of ability to apply the energy principle. Instead they answered the question based on observed physical features or properties directly provided from the given question. Students who chose the incorrect choice (Option B) tended to have a very superficial understanding of the energy concept.

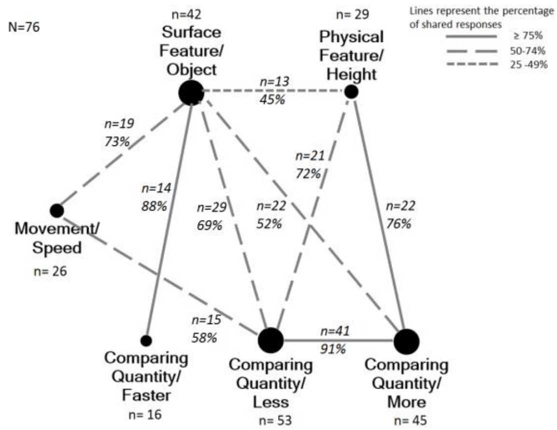


Figure 6. Web diagram for responses of students who chose the option B

The example responses are as followings.

> *Student D:* Once the ball is rolling, it will increase because of the incline position of the track and they begin to decrease where it is at the lower part of the track.
>
> *Student E:* When the ball is first rolled the total energy will increase as it gets higher up the ramp. But eventually decreases due to no force acting on it and the friction the track exerts on the ball.
>
> *Student F:* The energy increases first because it is going down the track and picks up energy and then eventually as the ball keeps going it will decreases and come to a stop.

The three example responses presented that Student D, E, and F focused on the movement of the ball on the track (nodes: Surface Feature/Object, Movement/Speed, and Comparing Quantity/Faster). Also, they used the information such as a position of the ball on the track to determine the amount of energy (nodes: Physical Feature/Height, Comparing Quantity/Less and Comparing Quantity/More, link: between Physical Feature/Height and Comparing Quantity/More or Less). In their responses, the energy principle and energy transformation idea were not utilized. For example, student E and F mentioned that the amount of energy will eventually decrease but they did not explain why it will happen. Rather, the direct information such as how the ball's position is changed on the track was used to determine the amount of energy in the system.

Discussion

In this study, students' responses to two energy questions were analyzed to investigate what information and key ideas students used in explaining their reasoning. The purpose of the first question was to assess students' ability in identifying energy forms and provide relevant evidence associated with the specific energy form in their explanations. The second question was designed to assess students' ability to apply energy principles and provide rationales to support their claims on how the energy principle, e.g., energy conservation, can be applied to the given situation.

The result from question 1 showed that students who focused mainly on surface-level information, e.g., flat road, identical cars, or same speeds, failed to answer the question correctly, while students who used scientific ideas, such as the energy concept, along with information provided in the question, e.g., different height roads, were more likely to provide a correct answer. In other words, students who chose the incorrect option generally focused on the surface features provided in the question, and did not connect the height difference to the car's potential energy.

The analysis results of question 2 revealed that students who chose the correct answer (the total energy will be the same) used the energy principle and the idea of energy transformation significantly more than students who chose the incorrect choice. This finding was aligned with the question 1 analysis result in that students' ability to apply the energy concept and principle was critical to solving energy questions successfully. This also supports the idea that students who focused on the superficial information provided in the question, but did not connect those ideas to the energy concept were likely to fail to answer the question correctly.

Note that, although students who selected the correct option in the multiple choice component used the energy principle in their responses, this study found little evidence that students possessed integrated understanding of the energy degradation and conservation ideas. Rather students showed fragmented understanding with isolated ideas. As shown in the web-diagrams (see Figure 5), not all students who used the energy principle mentioned energy transfer/transformation concept, which should precede understanding of the energy principle (Lee & Liu, 2010; Liu & McKeough, 2005). In addition, only a few students incorporated ideas of friction, heat, or thermal energy into their responses. This result implies that students might answer the question by rote memorization of the principle as opposed to deeper understanding. Biggs and Collis (1982) defined a five level learning cycle, the SOLO taxonomy that represent the five different ways in which students respond. Question 2 in particular addressed the energy principal and required higher knowledge integration levels (Lee & Liu, 2010). Thus, it was expected that students who successfully answered question 2 would demonstrate their ability in connecting factual ideas in their responses (i.e., "Relational" responses) (Biggs & Collis, 1982). However, most responses only contained isolated ideas (i.e.,"Unistructural" or "Multistructural" level responses). This findings implies that students answered the question only based on a few limited and independent ideas without integration (Biggs & Collis, 1982).

In sum, this study showed that students who focused on surface-level features of information in the given questions and did not connect the information to scientific concept failed to answer correctly, while students who used the underlying energy concept were more likely to answer the question successfully. The findings from this study can inform educators about students' difficulties in applying energy concept to a certain situation. For example, this study provided further insight about students' difficulty in applying energy concept when an object is moving on a flat road. Although one road is located higher than the other one, many students failed to connect the height difference to a different amount of gravitational potential energy. The findings of the study also suggest that educators focus on guiding students to connect factual ideas to scientific concept. Many students used surface-level features of information directly provided from a given question to answer the question, however they failed to apply scientific concept to integrate the information. It is recommended that educators introduce different situations to students and help them find relevant information and connect them to scientific concept.

There are several limitations to this study. Because responses were collected from student enrolled at least one introductory level science course in a college, it is difficult to generalize to other populations of students. Multiple forms of the different questions, e.g., different examples, different formats of a question, were not administered to the students, so the result might be affected by specific item features used in this study. Lastly, it is important to conduct student interviews to elicit student conceptual understanding for these questions and to provide more evidence for supporting the findings, which will be performed in future studies.

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