Using Multiple Representations to Teach Energy– An Alternative Conceptual Approach

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Abstract
Energy is a principal concept in the learning of Physics, yet it is a concept that students found abstract and challenging to grasp, especially the key ideas of Transfer, Transform and Conservation. This paper proposes that a multiple representation approach in the teaching and learning of this topic helps support and deepen students' learning of the topic. Qualitative and quantitative treatments have their place in the multiple representations of energy, which allows teachers to scaffold students' learning for deeper understanding, and enable students to demonstrate their knowledge. This evidence-based sharing will illustrate how representations such as Energy Bar Diagram (LOL) and Energy Cube manipulative are used to (i) quantify conservation of energy (ii) show energy transformation within bodies, and (iii) quantify energy distribution and energy transfer between interacting bodies.

Keywords: Physics, Energy, Multiple Representations, LOL, Energy Cubes

1. Introduction

Physics is the study of interactions and transfer of energy between matter. "Energy" is an abstract concept for students to grasp. To deepen students' learning of this topic, the Professional Learning Team (PLT) at Yusof Ishak Secondary School and Academy of Singapore Teachers proposes a multiple representations approach to teaching and learning as well as in problem-solving.

In line with the Singapore Curriculum Philosophy, the "multi-modal" approach to teaching and learning "Energy" recognises that every student can learn and has different strengths which can be engaged in multiple ways.

There has been an ongoing discussion in the literature on how energy should be taught. Energy is a difficult concept to teach for two reasons (Millar, 2005):

- it is an abstract mathematical concept which is difficult to be defined;
- it is used in everyday contexts in a way which is less than precise than its scientific meaning e.g. "energy is used up" makes it sounds like energy is not conserved.

Locally (Lau, et. al 2011), it has been reported that some students' common alternative conceptions are:

- energy is either a physical substance that flows out of one thing to another or as a kind of force;
- work done represents energy stored in a body;
- energy is used up or lost during interactions.

WestEd Science Review (2011) reported some of the common alternative conceptions as follows:

- energy is deemed to be something physical or made of matter;
- energy is a force;
- energy is involved only when objects are moving or things are changing;
- energy transfers are perfectly linear in the sense that one event triggers only one energy ransfer.

Table 1: Summary of Common students' learning difficulties and alternative conceptions

Common students' learning difficulties	**Common students' alternative conceptions**
-It is an abstract mathematical concept which is difficult to be defined. -It is used in everyday contexts in a way which is less precise than its scientific meaning.	-Energy is either a physical substance that flows out of one thing to another or as a kind of force. -Work done represents energy stored in a body. -Energy is used up or lost during interactions. -Energy is involved only when objects are moving or things are changing. -Energy transfers are perfectly linear in the sense that one event triggers only one energy transfer.

Therefore, it is important for teachers to be aware of students' learning difficulties and to surface the students' preconceptions/misconceptions (see **Table 1**) of the topic on energy and use this data to design their teaching approach. To have an accurate understanding of energy, it is important to address the 5 important concepts as listed below:

- Defining different objects of interest and different initial state and final state will surface different energy data for analysis.
- In different state of the object, energy is called different names.
- Every interaction involves a transfer of energy during a timeframe of interest.
- Force is produced by the interaction between objects.
- Work done is a form of energy transfer by a force that is acting over distance. It is possible to know how much work has been done by calculating the change in energy during an interaction.

To facilitate the teaching and learning of the above 5 key concepts and to help overcome the learning difficulties and challenges, we layered in both the qualitative and quantitative treatments in a multiple representations approach. This would allow teachers to scaffold students' learning for deeper understanding. Students would be able to demonstrate their knowledge and make their thinking "visible" through this approach which will allow for teachers' quality feedback to students.

2. Lesson Preparation Considerations

This section presents the student's prior knowledge and the teaching ideas to be achieved in this approach. Knowing the prior knowledge and the teaching ideas to be taught allow teachers to design the energy lesson building on students' existing knowledge, hence achieving a better progression of learning.

2.1 Prior knowledge

At the primary level, Singapore students learn that energy:

- is required to make things work or move and energy from most of our energy resources is derived in some ways from the Sun, our primary source of light and thermal energy.
- exist in different forms e.g. kinetic energy (movement energy), gravitational potential energy (objects above the ground), elastic potential energy (spring, elastic band), light energy, electrical energy, sound energy, thermal energy and chemical energy (as a form of stored energy: food, batteries, fuels).

At the lower secondary level, they learn that:

- work is the use of a force to move an object.
- energy is the ability (or capacity) to do work or to produce change (work done = energy used) and there are different forms of energy e.g., kinetic, potential, light and sound.
- energy is conserved and can only change from one form to another (the total amount of energy before and after the change is exactly the same).
- sources of energy include fossil fuels (coal, oil, gas), kinetic energy from water and wind, nuclear, solar, and biomass.

2.2 Teaching ideas

In the course of their learning, students must be able to articulate the following key ideas:

- Energy can be categorised generally into two groups – energy of motion and energy of relative position.
- Energy can be quantified.
- Energy is a numerical quantity that is conserved during interactions (in a closed system).
- Energy can transform from one form to another during an interaction.
- Mechanical work is a pathway of energy transfer during an interaction and can be calculated using *work done = force × distance*.

The remainder of this paper presents how the team go about the teaching of energy at upper secondary level. We adopted Content Representation (Loughran et al., 2012), CoRe for short, as a tool to develop our pedagogical content knowledge (PCK) in the teaching of energy. In particular, the methodology of CoRe helped us in clarifying the big teaching ideas for the topic and develop unique strategies that support students' learning via multiple representations approach (See **Appendix 1**).

2.3 The multiple representations

These multiple representations approach in teaching is deployed using qualitative and quantitative treatments

2.3.1 Qualitative treatment

The team began teaching the topic on energy by eliciting students' prior knowledge and take the opportunity to address some students' alternative conceptions about energy.

Among scientists, there is no standardized way to categorise energy, nor is there a single convention for naming the various types of energy. Nevertheless, the team have adopted the approach by WestEd (2011) to classify energy in terms of *energy of motion* and *energy of (relative) positions*.

The team utilised the use of whiteboarding as a constructivist approach to allow students to explain what they think energy is. During this activity, the teacher played the role of a facilitator, bearing in mind that the students have brought with them a set of prior knowledge and alternative conceptions.

Considerable amount of time was spent with the students to reflect on the definition of energy. Teacher developed the concept that energy is a mathematical construct created by scientists to describe how much change can happen in a system. Teacher co-constructed a definition with students that includes the idea of energy being a numerical quantity that is conserved during interactions.

Teacher steered the students towards a definition of energy. Some of the more accurate and precise definitions of energy to teach the students are (WestEd, 2011):

- Energy is a measure of how much change can happen in a system. It is a quantity that is conserved despite the many changes that occur in the natural world.

- Energy is the amount of work required to change the state of a physical system. The numerical amount of energy of a system diminishes when the system does work on any other system.
- Mathematically, energy is a numerical quantity that does not change when an interaction happens in a closed system.

An example of a definition formed was to define "energy as a measure of how much change has occurred due to position or motion during an interaction between bodies."

The qualitative categorisation of energy and derivation of an energy definition form the foundations for quantitative approach in problem solving.

See **Appendix 2** for the worksheet used by the team to construct students' understanding about energy.

We felt that it is important in the analysis of energy transformations to bring in the idea of system. Most teachers would struggle with the thought of introducing "system" to students. However, during the course of interactions with our students, we realised the usefulness and importance of identifying the objects of interest, the forces involved and the specific timeframe during an event, a process or an interaction when analysing energy conversion. In fact, the identification of objects, forces and timeframe defines the system of interest. So, the idea of system does not need to be introduced formally if only when an accurate and deeper analysis of energy conversion allows it to emerge naturally.

Another interesting area of discussion with the students is the relationship between force and energy. This is a necessary discussion because students are confused between gravitational force and gravitational potential energy. While the mathematical formula can be used to highlight their differences, a fundamental understanding of their differences is necessary. It is important to highlight that force is the cause of the change in position or motion but energy is just a numerical quantity that is assigned to the system or objects of interest, and this number is conserved at all times. Energy is not the cause of the change in position and motion of the object of interest. This is a teachable moment to remind students that energy cannot be created or destroyed.

As always, we could conclude the qualitative discussion by consolidating the learning points.

See **Appendix 3** on how it might look like.

2.3.2 Quantitative treatment

Both the qualitative and quantitative treatments are interdependent and necessary to foster deep understanding. To aid in the quantitative understanding of energy, teachers can provide multiple means of representation:

Representation 1: Using *energy flow diagram* to analyse energy conversion/transfer (See **Figure 1** below).

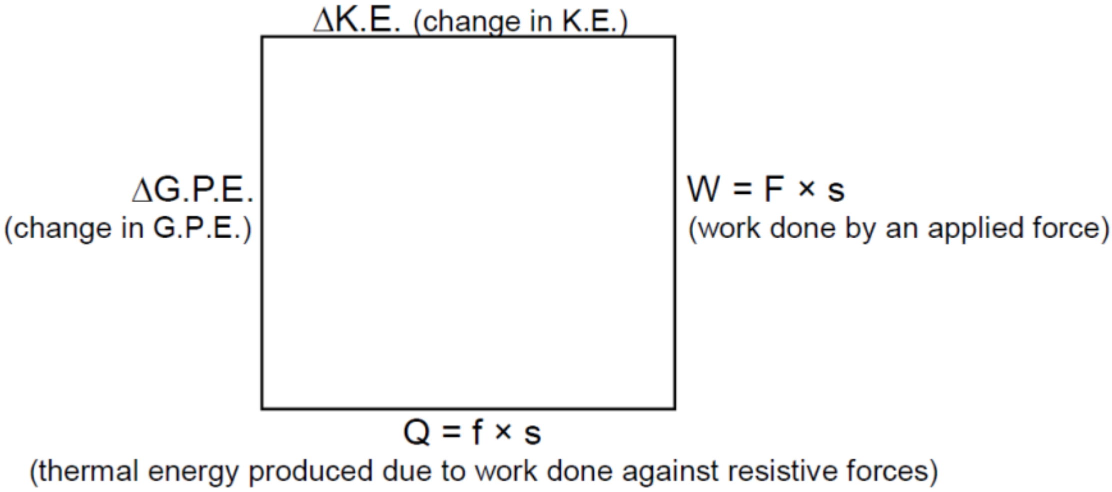

Figure 1: Energy flow diagram

With the help of the energy flow diagram, students can learn how to express the equation for energy conversion mathematically. They should also be taught to describe and explain the energy transfer that takes place conceptually in their own words.

Representation 2: Using *energy bar chart* to quantify conservation of energy during interactions (at the initial and final states). See **Figure 2** below.

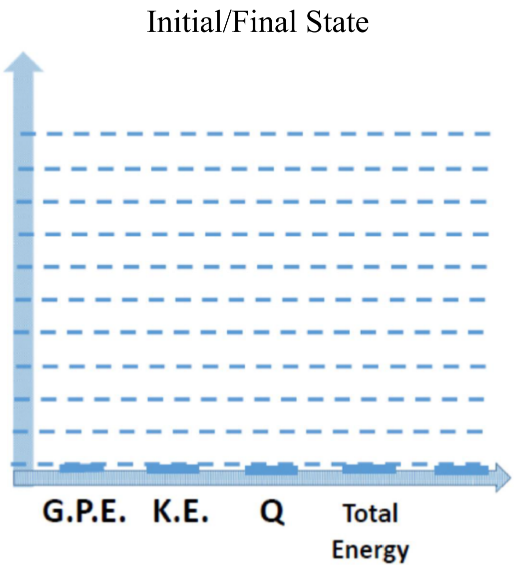

Figure 2: Energy bar chart

An energy flow diagram can also be combined with the energy bar charts of the initial and final states to form a so-called *LOL diagram* see **Figure 3** below.

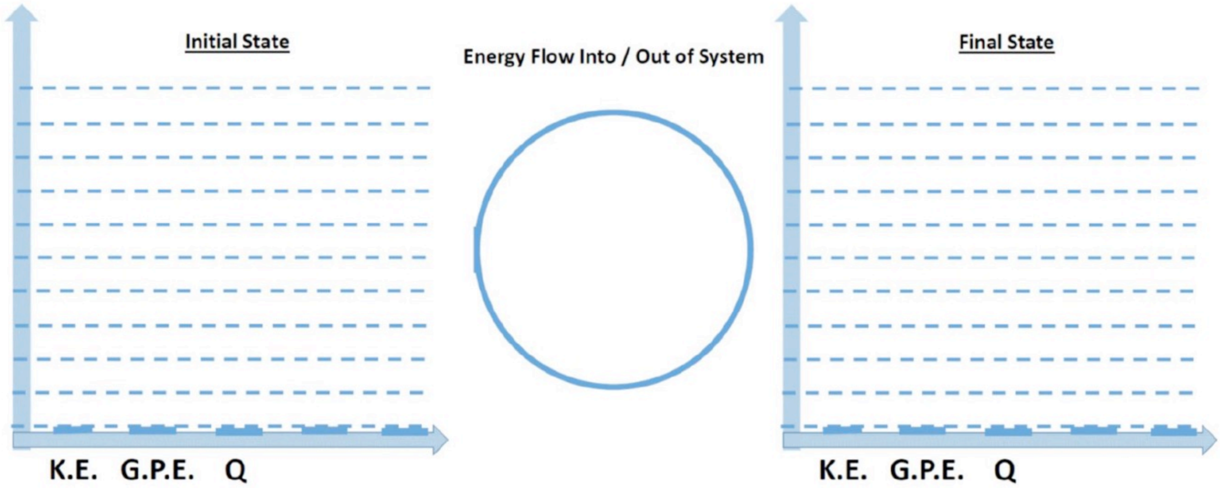

Figure 3: The LOL diagram

The concept of energy transformation can be reinforced here, and importantly, the Principle of Conservation of Energy (COE) can also be introduced quantitatively and illustrated with the energy bar charts or LOL using total energy at the initial state + energy transfer into the system = total energy at the final state + energy transfer out of the system. Where work is involved, the idea of work as amount of energy transfer/converted can be easily illustrated using LOL.

Representation 3: Using *energy cubes* (See **Figure 4**) to quantify forms of energy and to help in visualising interactions between objects of interest in a specific timeframe of interest (in a system). The energy cube has six sides, each side has a form of energy attached to it, the top face represents the form of energy associated with an object of interest at a particular define state (Initial/final).

Figure 4: An energy cube. This energy cube is representing 1 unit of kinetic energy

The energy cube provides another option for "physical" expression of understanding of COE, making students' thinking more visible for teachers to give more accurate feedback. Every representation has its limitation. Likewise, it is important to highlight to the students the limitations that the energy cube does not suggest that energy is an object or exists as something physical. Take the opportunity to emphasise that energy is a numerical quantity that is conserved during interactions between bodies.

3. Lesson Enactment

Here, we shall briefly describe how the energy flow diagram, energy bar chart or LOL and energy cubes can be used for teaching and learning in a lesson. To make connection with the new world application, hence making it more meaningful for the students, a real-world scenario or authentic case study has to be deployed. To arouse interest, students can be involved in the process of deciding on a case study. For us, we chose the re-entry of Tiangong 1 (on 2 April 2018) as the case study (see **Appendix 4**).

3.1 Introduction (framing the learning)

Set the context for the real-world scenario or authentic case study (e.g., re-entry of Tiangong 1). Present qualitative / quantitative data to students for sense making (e.g., high temperature during re-entry leading to vaporisation of components).

3.2 Hands-on / minds-on using multiple representations

Identify the objects of interest, the forces involved and specific timeframe of interest for the energy transfer during interaction. In their own groups, students shall use energy flow diagram, LOL and energy cubes to describe the transfer of energy and account for the Conservation of Energy. Students shall present the group findings in class discussions. See **Appendix 5** for a sample of group presentation.

3.3 Checking for understanding

The suggested success criteria are:
Students are able to:

- identify the forces and objects of interest that are present during interactions,
- describe the energy transformation/energy transfer (using energy bar chart and energy cubes),
- demonstrate that total energy is conserved (using energy flow diagram and energy bar chart).

See **Appendix 6** for a sample of worksheet on checking for understanding.

A lesson plan on the energy study of re-entry of Tiangong 1 can be found in **Appendix 7**.

4. Making connections

The topic on energy cannot be learnt in isolation, and it is important for students to see the connections between energy and earlier topics of Newtonian Mechanics, i.e. kinematics and dynamics. Students have to be adept in using different representations, e.g. force diagrams, velocity-time graphs, mathematical equations, word descriptions, energy flow diagram, to solve problems in Newtonian Mechanics. As energy is a principal concept that appears in subsequent topics like thermal physics and waves, it is definitely a meaningful and worthwhile endeavor to invest considerable amount of time and attention in the teaching of energy. See **Appendix 8** for a sample of the worksheet used in our classes.

5. Feedback from teachers and students

A ‘demonstration class/workshop on “A Conceptual Approach in Teaching of Energy Using Multiple Representations” with lesson design described above was conducted at Centre for Teaching and Learning Excellence (CTLE), Yusof Ishak Secondary School, in 2018, 2020 and 2022 for a group of pre and in-service physics teachers and teacher leaders. In post-demo class discussion and their written feedback, teachers agreed that CoRe was a useful design for reflective practice and developing the pedagogical content knowledge on teaching energy. They affirmed that the multiple representations approach help students to learn better. They also acknowledged that energy flow diagram, energy bar and energy cubes were useful teaching aids that could support students in their learning.

Quantitative (four-point Likert scale) and qualitative feedback that were collected from the students and teachers were encouraging too.

5.1. Impact on students

A survey (See Appendix 9) was conducted at Centre for Teaching and Learning Excellence at Yusof Ishak Secondary School on 41 upper secondary physics students over 2018 and 2019 showed positive qualitative and quantitative responses on the use of this multiple representations approach.

The average Quantitative (four-point Likert scale): A high rating of **3.60** out of 4.00 is obtained.

Table 2: Student quantitative survey (Likert scale of 1 [strongly disagree] to 4 [strongly agree]) on the learning activities of the Energy lessons using multiple representations

Learning Activities	Mean
I learn better when lessons are conducted using models.	3.61
Hands-on using models with discussion in groups to verify teacher’s teaching improves my understanding of the lesson.	3.68
Explaining my individual/group’s answers to my group/class helps me to clarify what I understand/do not understand.	3.51
The lesson activities make it easier for me to understand the Law of Conservation of Energy.	3.61

Some qualitative feedback from the students is highlighted below:

Use of Models

- Engaging and interesting
- Easy to follow teacher’s instructions
- Able to understand/visualise better with the models
- The demo was clear and easy to understand
- Demos are easy to visualize
- Able to see better in physical form
- Allows students to engage/participate actively

Deeper Understanding

- Activities allowed more clarification on issues faced and helps in understanding concepts
- There were many hands-on activities which is what I like as it is easy for me to remember
- Help me to understand better
- Easier to consolidate learning using the energy cube
- Lots of hands-on activities, gain more knowledge of the energy

5.2. Impact on teachers

A survey (See **Appendix 10**) was conducted on 73 Physics teachers who attended the demonstration classes in 2018, 2020 and 2022 also showed positive qualitative and quantitative responses on the use of this multiple representations approach.

Workshop rating: A high rating of 3.44 out of 4.00 is obtained.

Some Qualitative feedback from the teachers (useful ideas participants would like to apply back in their own classrooms) are highlighted below:

- Use of Multimodal representations
- Use of Energy flow diagram
- Use of CoRe in design for understanding
- Using of energy cubes & Energy Bar Chart (LOL) to help with visualisation
- Linking force and energy
- Use of energy cube to quantify and also show the transfer/transformation of energy.
- Enhance understanding of Conservation of Energy
- Use of multiple representation to help students learn
- The use of LOL and energy flow diagram as representation
- Interesting use of tiangong-1
- Use of the cube to redesign the lesson on energy.
- Use energy cube to teach abstract idea
- Use of change in energy
- Use of energy cube to teach concept of energy conversion and conservation
- Use of energy charts and energy cubes to help students understand ideas of energy stores and energy transfer
- The new idea of energy stores
- Very revolutionary ways of teaching energy.
- Using props like energy cubes to generate communications
- Teaching energies in terms of stores and the different modes of representation
- The scenario cards are innovative.
- The multiple representations for students to visualize and the LOL chart
- Terms used in energy stores and how energy is transferred in and out of the system.
- The energy cubes is a good demonstration that energy is conserved

Conclusion

Energy is a principal concept in the learning of Physics, yet it is a concept that students found abstract and challenging to grasp. Teachers can provide multiple means of representation by using (i) energy flow diagram to analyse energy conversion, (ii) energy bar chart to quantify conservation of energy during interactions and (iii) energy cubes to quantify energy distribution between interacting bodies as well as to reinforce principles of conservation of energy.

As energy cannot be learnt in isolation from kinematics and dynamics, it is important for students to see the connections between these concepts. Therefore, it is worthwhile to invest time and attention in ensuring that students are adept at using different representations like force diagrams, velocity-time graphs, mathematical equations, word descriptions, energy flow diagram, to solve problems in Newtonian mechanics.

These multiple representations approach can be digitalized (self-assessing teaching app) for self-directed learning. This approach can also be modified to teach Energy using a pedagogical framework of Energy Stores (e.g. Kinetic energy store, Potential energy store, Nuclear energy store, Chemical energy store, Nuclear energy store and Elastic energy store) and four Energy transfers pathways (mechanically, electrically, propagation of waves and temperature difference). This pedagogical framework of energy stores and energy pathways and multiple representations approach allow the important ideas about interactions through forces and field to be featured more strongly.

Moving forward, the mass production and National wide implementation of the physical model (Energy Cube, LOL Energy Bar Diagram) in collaboration with Curriculum Planning & Development Division (CPDD) and the dissemination of the digital model through the Senior Teacher-Lead Teacher Network allow for scalability across all schools.

Appendix 1: Content Representation (CoRe)- Tool for developing pedagogical content knowledge (PCK)

Content Representation (CoRe) – Energy and Work

Teaching Ideas in Physics (TIPs)	• **Energy can be categorised generally into two well-accepted types – energy of motion and energy of relative position** • **Energy can transform from one form to another during an interaction** • **Energy is a quantity that is conserved during interactions (in a closed system)**	• **Energy can be quantified**	• **Work is a measure of change in energy during an interaction**
What you intend the students to learn about this idea?	(a) show understanding that kinetic energy, potential energy (chemical, gravitational, elastic), light energy, thermal energy, electrical energy and nuclear energy are examples of different forms of energy (b) state the principle of the conservation of energy (c) apply the principle of the conservation of energy to new situations or to solve related problems (d) calculate the efficiency of an energy conversion using the formula efficiency = energy converted to useful output / total energy input	(e) state that kinetic energy $E_k = ½ mv^2$ and gravitational potential energy $E_p = mgh$ (for potential energy changes near the Earth's surface) (f) apply the relationships for kinetic energy and potential energy to new situations or to solve related problems	(g) recall and apply the relationship *work done = force × distance moved in the direction of the force* to new situations or to solve related problems (h) recall and apply the relationship *power = work done / time taken* to new situations or to solve related problems
Why it is important for students to know this?	– Various types of energy result from objects moving or from the positions of one object in relation to the position of another object – In different parts of systems, energy is called different names – Thinking about energy as having different types helps us understand what is occurring in systems	– Every interaction involves a transfer of energy during a timeframe of interest – Force is present whenever there is transfer of energy, however, force is not the cause for transfer of energy – Not every system is ideal; some energy is transformed to other forms of energy e.g. thermal energy which cannot be utilised	– Work can be a measure of the energy transferred by a force that is acting over distance – It is possible to know how much work has been done by calculating the change in energy during an interaction

Physics Professional Learning Team 2018 Semester 1 / Centre for Teaching and Learning Excellence @ Yusof Ishak Secondary School

Content Representation (CoRe) – Energy and Work

Teaching Ideas in Physics (TIPs)	• **Energy can be categorised generally into two well-accepted types – energy of motion and energy of relative position** • **Energy can transform from one form to another during an interaction** • **Energy is a quantity that is conserved during interactions (in a closed system)**	• **Energy can be quantified**	• **Work is a measure of change in energy during an interaction**
What else you know about this idea (that you do not intend students to know yet)	– A system is defined by the objects of interest and forces of interest present in a timeframe of interest – Closed system – Energy is a measure of how much change that can happen in an interaction (that can happen in a system)		– Work is a measure of change in energy during an interaction – Refer to WestEd on limitations of the "official definition" of Work – Second Law of Thermodynamics
Difficulties / Limitations connected with teaching this idea	– Energy is an abstract concept	– Energy as a measure of the capacity of an object or system to do work is true only in certain situations	– Product of force and distance moved is a precise operational definition for mechanical work
Knowledge about students' thinking which influences your teaching of this idea	– Energy is involved only when objects are moving or things are changing – Energy is a substance or a physical object – Energy is a cause – Energy is fuel – Energy is force – Energy is power – Energy can be created or destroyed – Energy transfers are perfectly linear i.e. one event triggers only one event		– It is possible to do all kinds of work when energy is present
Other factors that influence your teaching of this idea	– It is more useful to define a start and end states rather than get caught up in the intermediate states when using energy transformations or considering energy changes	– Sometimes it is more useful to consider changes in amount of energy rather than thinking about amount of energy in a particular place or form	– Sometimes it is more useful to talk about rate of energy transfer rather than thinking about amounts of energy in different places or forms

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Content Representation (CoRe) – Energy and Work

Teaching Ideas in Physics (TIPs)	• **Energy can be categorised generally into two well-accepted types – energy of motion and energy of relative position** • **Energy can transform from one form to another during an interaction** • **Energy is a quantity that is conserved during interactions (in a closed system)**	• **Energy can be quantified**	• **Work is a measure of change in energy during an interaction**
Teaching procedures (and particular reasons for using these to engage with this idea)	– Elicit prior knowledge – Address misconceptions – Use of whiteboarding (constructivist approach) to allow students to explain what energy is – Use of "energy flow diagram" to solve qualitatively and quantitatively problems related to PoCE		
	– Debunking misconceptions about energy – Introduce the concept of energy – Classify energy into 2 types – energy of relative positions and energy of motion	– Energy can be transformed; introduce energy transformation (start and end of a process/interaction) – Introduce Principle of Conservation of Energy using Total Energy at start = Total Energy at the end – Solve problems using PoCE and "energy flow diagram" – Analyse energy transfer using "energy flow diagram" – Connect concept of work and amount of energy converted	
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	– Use of diagnostic test for intervention and extent of meeting learning outcomes – Use of "energy flow diagram table" to solve qualitatively and quantitatively problems related to PoCE		

Appendix 2: Sample learning activities for providing progression of learning and surfacing students' preconceptions (this is presented in worksheet format)

1. List down at least 6 different types of energy you encounter in your everyday life and/or read in newspapers and books.

2. Classify the list into 2 categories:

Energy due to relative positions	**Energy due to motion**

3. Describe what you think energy is or what it means to you.

4. Write down the energy transfer of the motion of a toy car powered by batteries.

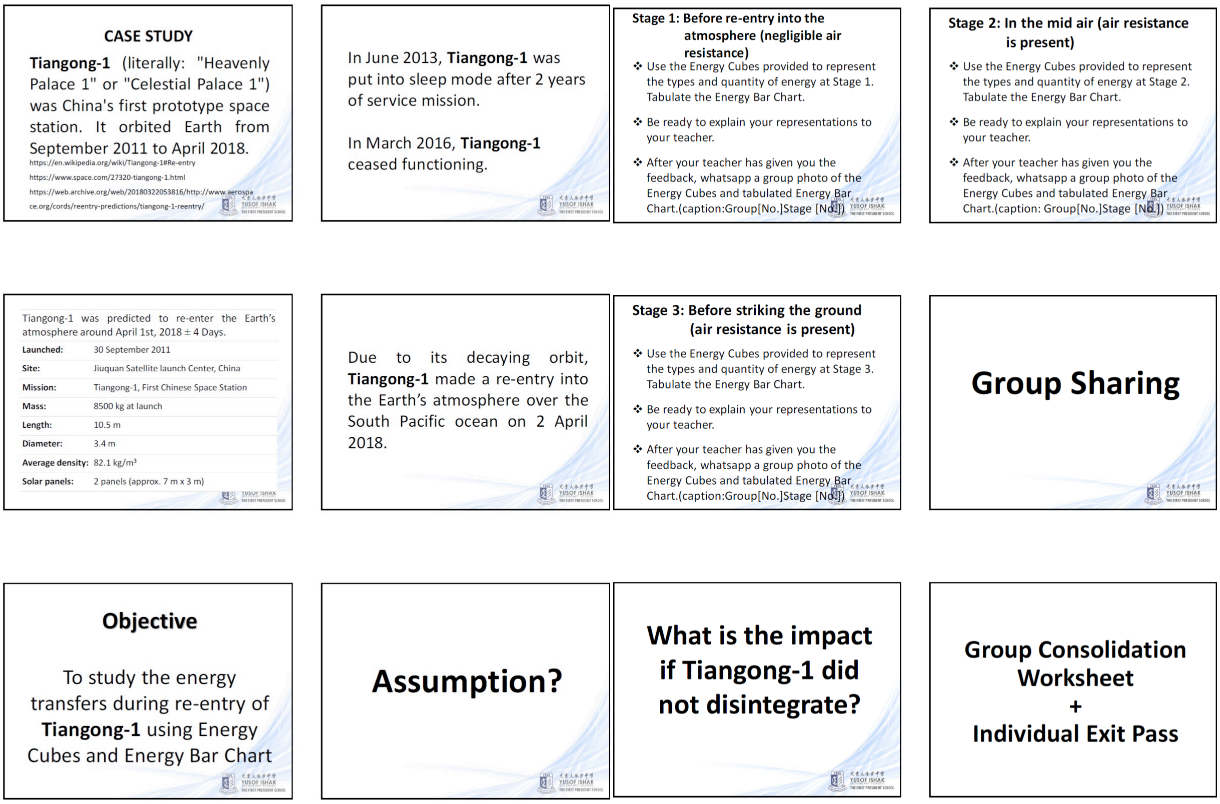
5. Consolidation of learning.

Appendix 3: Key learning points/Teaching Ideas to be accomplished in this energy curriculum

What we have learnt about Energy

1. Energy is a measurable quantity, a number, that describes how much change can happen in a system.
2. It is a quantity that is always conserved.
3. Energy transfers occur during interactions. As a result of an interaction, energy can change from one type to another.
4. Force is produced by the interaction between objects.
5. A system can be defined by identifying the objects of interest and the forces of interest within a specific timeframe of interest.

Appendix 4: The lesson slides using the re-entry of Tiangong 1(Decommissioned space station) as a real-life application for analysis of Energy Changes.



Appendix 5: Sample students' cooperative learning work, using multiple representations (white boarding, energy bar diagram, diagrams with explanations, energy cube)

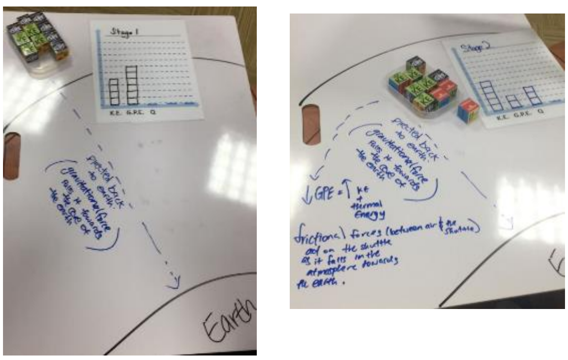


Figure A5.1: Left picture: Multiple representations of energy data at stage one of space station reentry as presented by students and Right picture: Multiple representations of energy data at stage two of space station reentry as presented by students.

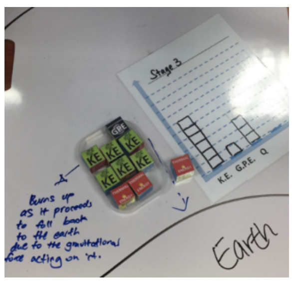
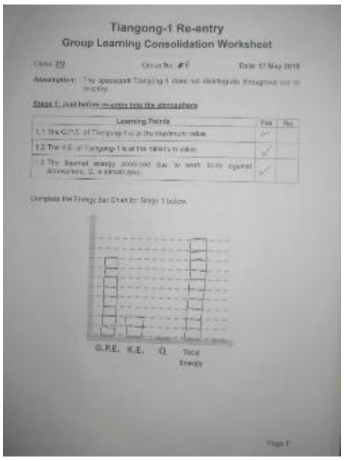


Figure A5.2: Multiple representations of energy data at stage 3 of space station reentry as presented by students.

Appendix 6: Sample students' group submission for their reflection and consolidation of their learning journey and exit pass, using multiple representations (energy bar diagram, diagrams and energy flow diagram)



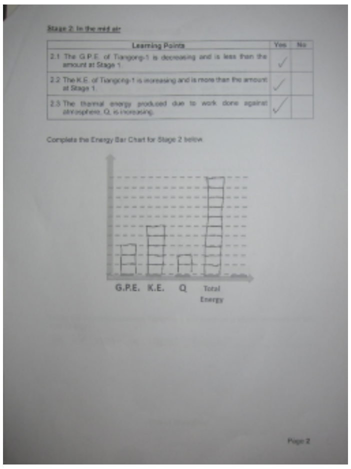
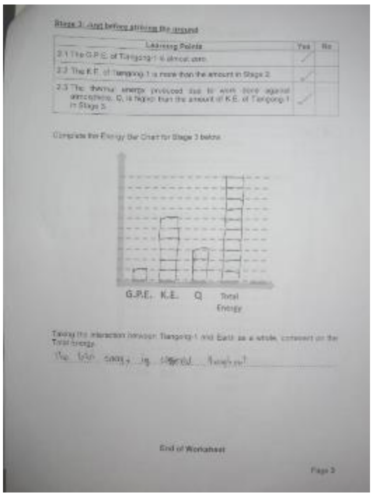


Figure A6.1: Sample group work of students' using energy bar diagram and checklist for consolidating learning. Left picture: stage 1 of space station reentry and Right picture: stage 2 of space station reentry



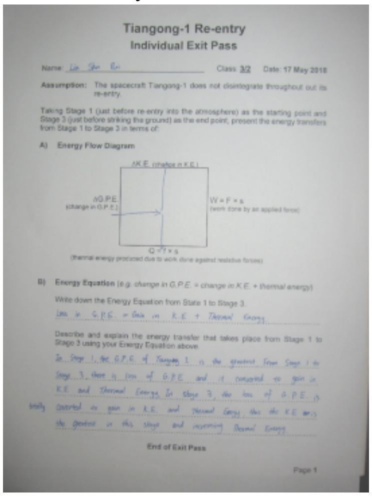
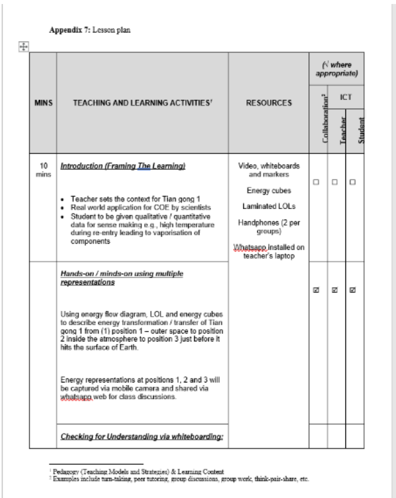


Figure A6.1: Left picture: Sample group work of students' using energy bar diagram and checklist for consolidating learning at stage 3 of space station reentry and Right picture: Exit pass for the whole learning activity.

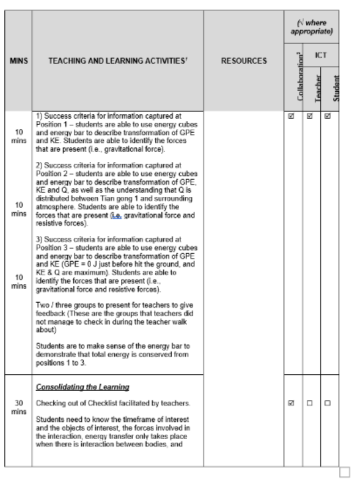
Appendix 7: Lesson plan



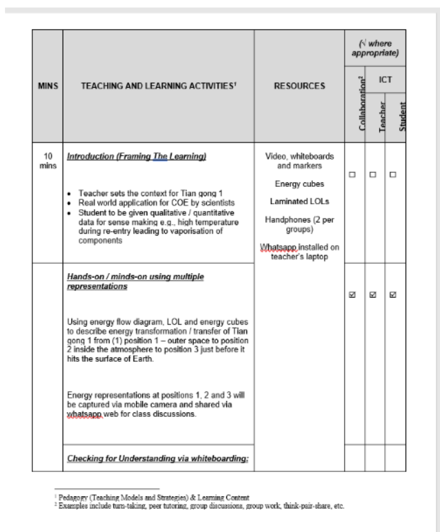
Appendix 7: Lesson plan

MINS	TEACHING AND LEARNING ACTIVITIES[1]	RESOURCES	(√ where appropriate) Collaboration[2]	ICT Teacher	ICT Student
10 mins	***Introduction (Framing The Learning)*** • Teacher sets the context for Tian gong 1 • Real world application for COE by scientists • Student to be given qualitative / quantitative data for sense making e.g., high temperature during re-entry leading to vaporisation of components	Video, whiteboards and markers Energy cubes Laminated LOLs Handphones (2 per groups) Whatsapp installed on teacher's laptop	☐	☐	☐
	Hands-on / minds-on using multiple representations Using energy flow diagram, LOL and energy cubes to describe energy transformation / transfer of Tian gong 1 from (1) position 1 – outer space to position 2 inside the atmosphere to position 3 just before it hits the surface of Earth. Energy representations at positions 1, 2 and 3 will be captured via mobile camera and shared via whatsapp web for class discussions.		☑	☑	☑
	Checking for Understanding via whiteboarding:				

[1] Pedagogy (Teaching Models and Strategies) & Learning Content
[2] Examples include turn-taking, peer tutoring, group discussions, group work, think-pair-share, etc.



MINS	TEACHING AND LEARNING ACTIVITIES[1]	RESOURCES	(√ where appropriate) Collaboration[2]	ICT Teacher	ICT Student
10 mins 10 mins 10 mins	1) Success criteria for information captured at Position 1 – students are able to use energy cubes and energy bar to describe transformation of GPE and KE. Students are able to identify the forces that are present (i.e., gravitational force). 2) Success criteria for information captured at Position 2 – students are able to use energy cubes and energy bar to describe transformation of GPE, KE and Q, as well as the understanding that Q is distributed between Tian gong 1 and surrounding atmosphere. Students are able to identify the forces that are present (i.e. gravitational force and resistive forces). 3) Success criteria for information captured at Position 3 – students are able to use energy cubes and energy bar to describe transformation of GPE and KE (GPE = 0 J just before hit the ground, and KE & Q are maximum). Students are able to identify the forces that are present (i.e., gravitational force and resistive forces). Two / three groups to present for teachers to give feedback (These are the groups that teachers did not manage to check in during the teacher walk about) Students are to make sense of the energy bar to demonstrate that total energy is conserved from positions 1 to 3.		☑	☑	☑
30 mins	***Consolidating the Learning*** Checking out of Checklist facilitated by teachers. Students need to know the timeframe of interest and the objects of interest, the forces involved in the interaction, energy transfer only takes place when there is interaction between bodies, and		☑	☐	☐



MINS	TEACHING AND LEARNING ACTIVITIES[1]	RESOURCES	(√ where appropriate) Collaboration[2]	ICT Teacher	ICT Student
10 mins	***Introduction (Framing The Learning)*** • Teacher sets the context for Tian gong 1 • Real world application for COE by scientists • Student to be given qualitative / quantitative data for sense making e.g., high temperature during re-entry leading to vaporisation of components	Video, whiteboards and markers Energy cubes Laminated LOLs Handphones (2 per groups) Whatsapp installed on teacher's laptop	☐	☐	☐
	Hands-on / minds-on using multiple representations Using energy flow diagram, LOL and energy cubes to describe energy transformation / transfer of Tian gong 1 from (1) position 1 – outer space to position 2 inside the atmosphere to position 3 just before it hits the surface of Earth. Energy representations at positions 1, 2 and 3 will be captured via mobile camera and shared via whatsapp web for class discussions.		☑	☑	☑
	Checking for Understanding via whiteboarding:				

[1] Pedagogy (Teaching Models and Strategies) & Learning Content
[2] Examples include turn-taking, peer tutoring, group discussions, group work, think-pair-share, etc.

	Hands-on / minds-on using multiple representations Using energy flow diagram, LOL and energy cubes to describe energy transformation / transfer of Tian gong 1 from (1) position 1 – outer space to position 2 inside the atmosphere to position 3 just before it hits the surface of Earth. Energy representations at positions 1, 2 and 3 will be captured via mobile camera and shared via whatsapp web for class discussions.		☑	☑	☑
10 mins 10 mins 10 mins	***Checking for Understanding via whiteboarding:*** 1) Success criteria for information captured at Position 1 – students are able to use energy cubes and energy bar to describe transformation of GPE and KE. Students are able to identify the forces that are present (i.e., gravitational force). 2) Success criteria for information captured at Position 2 – students are able to use energy cubes and energy bar to describe transformation of GPE, KE and Q, as well as the understanding that Q is distributed between Tian gong 1 and surrounding atmosphere. Students are able to identify the forces that are present (i.e. gravitational force and resistive forces). 3) Success criteria for information captured at Position 3 – students are able to use energy cubes and energy bar to describe transformation of GPE and KE (GPE = 0 J just before hit the ground, and KE & Q are maximum). Students are able to identify the forces that are present (i.e., gravitational force and resistive forces). Two / three groups to present for teachers to give feedback (These are the groups that teachers did not manage to check in during the teacher walk about)		☑	☑	☑
	Students are to make sense of the energy bar to demonstrate that total energy is conserved from positions 1 to 3.				
30 mins	***Consolidating the Learning*** Checking out of Checklist facilitated by teachers. Students need to know the timeframe of interest and the objects of interest, the forces involved in the interaction, energy transfer only takes place when there is interaction between bodies, and forces are present during interactions and transfer of energy.		☑	☐	☐

Appendix 8: Learning activity to help students to make connections to their understanding of motion of an object across the 3 topics of Dynamics, Kinematics and Energy.

A Study of Motions Using Kinematics, Dynamics and Energy

E.g. Students can present their understanding of the motion of objects of interest for:

1. an object undergoing downward vertical motion under the action of weight in the presence of air resistance;

2. for an object moving up an inclined plane under the action of an applied force in the presence of friction.

Dynamics	Kinematics	Energy, Work & Power
1. Draw free body diagram to show all forces acting on the body 2. Identify the net/resultant force acting on the body)	Describe the motion in terms of the acceleration and/or velocity-time graph	Describe in terms of energy flow diagram, energy bar diagram, energy transfer and principle of conservation of energy

Appendix 9: Student Survey

Student Survey 2018

(1) COURSE INFORMATION

Title of Session: Laws of Conservation of Energy: using Energy Flow diagram, Energy Bar Diagram and Energy Cube

Date(s) of Session: 17 May 2018

Class Code *(if applicable)*:

Conducted by *(delete accordingly)*: Mr Yap Boon Chien and Mr Donovan Lau

Facilitator(s):

Your feedback will assist us in future planning.
No of forms = 21
SQ Indicator = 3.59
(2) OVERALL FEEDBACK ON COURSE/WORKSHOP/SEMINAR/MASTER CLASS
Please shade/tick the appropriate circle.

	Comments on Course/Workshop/Seminar/Master Class	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
1.1	I learn better when lessons are conducted using models.	o	o	9 (42.9%)	12 (57.1%)	3.57
1.2	Hands-on models with discussion in groups to verify teacher's teaching improves my understanding of the lesson.	o	o	7 (33.3%)	14 (66.7%)	3.67
1.3	Explaining my individual/group's answers to my group/class helps me to clarify what I understand/do not understand.	o	1 (4.7%)	9 (42.9%)	11 (52.4%)	3.48
1.4	The lesson activities make it easier to me to understand the general wave properties.	o	o	8 (38.1%)	13 (61.9%)	3.62

11. Some strengths of the lesson:

- Engaging and interesting
- Activities allowed more clarification on issues faced and helps in understanding concepts
- Able to understand/visualise better with the models
- Easy to follow teacher's instructions
- Easier to consolidate learning using the energy cube
- Allows students to engage/participate actively

12. Some ways that this learning experience can be improved:

- More real-life scenarios to apply the energy cube (other than the parachute)
- Have competition between groups

Student Survey 2019

EVALUATION FORM
(using simulation/model kits)

Title of Lesson(s) : Laws of Conservation of Energy: using Energy Flow diagram,Energy Bar Diagram(LOL) and Energy Cube
Date(s) : 30 May 2019

Name of Teacher(s): Mr Donavan Lau and Mr Yap Boon Chien

1 Please give us your evaluation of the lesson by ticking the relevant box for every item below.

SA Strongly Agree A Agree D Disagree SD Strongly Disagree

Number of forms = 20

		SA	A	D	SD	Mean
1.1	I learn better when lessons are conducted using models.	**13 (65%)**	**7 (35%)**	**0**	**0**	**3.65**
1.2	Hands-on using models with discussion in groups to verify teacher's teaching improves my understanding of the lesson.	**14 (70%)**	**6 (30%)**	**0**	**0**	**3.70**
1.3	Explaining my individual/group's answers to my group/class helps me to clarify what I understand/do not understand.	**11 (55%)**	**9 (45%)**	**0**	**0**	**3.55**
1.4	The lesson activities make it easier for me to understand the Law of Conservation of Energy.	**12 (60%)**	**8 (40%)**	**0**	**0**	**3.60**

2 What are the strengths of the lesson(s)?

- **Through notes I can understand the lesson**
- **Make the lesson more interesting**
- **I can learn better**
- **The demo was clear and easy to understand**
- **Really encouraging**
- **Demonstrations**
- **Easy to understand**
- **There were many hands-on activities which is what I like as it is easy for students to remember**
- **The lesson is well conducted, I learned a lot from this lesson, teacher's explanations are clear**
- **Demos are easy to visualise**
- **Help me to understand better**
- **Hands on activity and easy to visualise**
- **Able to see better in physical form**
- **It is easy to visualise and understand using the models**
- **Enable students to visualise easily**
- **It is easy to visualise**
- **Understand better**
- **It is interesting, we can play with the cubes**
- **By doing demonstration to make us understand more**
- **Lots of hands on activities, gain more knowledge of the energy**

3 What are some suggestions for improvement?

- **Give more games activities**
- **Demonstrations from the teachers**
- **No, it is good enough**
- **There is nothing to improve on, everything is good**
- **More demo**
- **Can shorter the time**
- **I am not sure**
- **Maybe the lesson time can be longer**
- **More of these**
- **More demo on energy cubes**
- **Do not need. Good enough**
- **Extend the timing. Have more demonstrations**
- **More demonstrations**
- **Nothing**

Appendix 10: Teacher Survey from CTLE Demonstration Classes (2018, 2020 & 2022)

Teacher Survey 2018

Evaluation Form (Collated)

Title : Demonstration Class on Conceptual Approach in Teaching of Energy
Date: 17 May 2018

Usefulness	Q1 - 3	3.23
Satisfied	Q5 - 7	3.26

Comments on Course / Workshop / Seminar	SD	D	A	SA	SQ rating
The objectives of the workshop were achieved.	0	0	18	5	3.22
The learning resources supported me in my learning	0	0	16	7	3.30
I can apply the ideas/knowledge/skills learned from the workshop	0	0	19	4	3.17
The presentation was clear.	0	0	15	8	3.35
The workshop met my learning needs	0	1	15	7	3.26
I would recommend the workshop to my colleagues	0	0	17	6	3.26
The questions were adequately addressed	0	0	17	6	3.26
The facilitator is skilful at facilitating the participants' learning	0	2	13	8	3.26
	Too short	Just right	Too long		
The duration of the workshop was sufficient to meet its objectives	19	2	2		

Q10. Some useful idea(s) from the demonstration class which I would like to apply:
Multimodal representations
Energy flow diagram
Use of CoRe in design for understanding
Using of energy cubes & Energy Bar Chart (LOL)
Linking force and energy
Use of energy cube to quantify and also show the transfer/transformation of energy.
PCK
Energy cube
Enhance understanding of Conservation of Energy
Use of multiple representation to help students learn
LOL
The use of LOL and energy flow diagram as representation
Energy bar
Energy bar rather than cube
Interesting use of tiangong-1
energy cube
Usage of the energy cubes and bars to help with visualisation
Use of lol and energy cube

Teacher Survey 2020

(1) COURSE INFORMATION

Title of Course/Workshop/Seminar: Teaching Energy

Date(s) of Course/Workshop/Seminar: 11 August 2020

Class Code: NIL

Your feedback will assist us in future planning.

Your feedback will assist us in future planning.
No of forms = 10/13
SQ Indicator
Usefulness: 3.37
Satisfaction: 3.33

(2) OVERALL FEEDBACK ON COURSE/WORKSHOP/SEMINAR

Please shade/tick the appropriate circle.

	Comments on Course/Workshop/Seminar	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
1.	The objectives were achieved.	o	o	6 (60%)	4 (40%)	3.40
2.	The learning resources (e.g., videos, book chapters, websites, notes, lab protocols, etc.) supported me in my learning.	o	o	7 (70%)	3 (30%)	3.30
3.	I can apply the ideas/knowledge/skills learnt from the course/workshop/seminar.	o	o	6 (60%)	4 (40%)	3.40
4.	The presentation was clear.	o	o	6 (60%)	4 (40%)	3.40
5.	The course/workshop/seminar met my learning needs.	o	o	7 (70%)	3 (30%)	3.30
6.	I would recommend the course/workshop/seminar to my colleagues.	o	o	7 (70%)	3 (30%)	3.30
7.	The questions were adequately addressed.	o	o	6 (60%)	4 (40%)	3.40
8.	The facilitator is skilful at facilitating the participants' learning.	o	o	7 (70%)	3 (30%)	3.30
9.	The course/workshop/seminar/master class helped me to reflect on my classroom practices.	o	o	8 (80%)	2 (20%)	3.20
10.	The duration of the course/workshop/seminar was sufficient to meet the objectives of the course/workshop/seminar.	**Too short** 1 (10%)	**Just right** 8 (80%)	**Too long** 1 (10%)		

10. Some useful idea(s) from the course/workshop/seminar which I would like to apply:

- Use of the cube to redesign the lesson on energy.
- The cube for visual learning.
- Use of the cubes and chart.
- Use energy cube to teach abstract idea
- Bar chart and change in energy
- Using of multiple representations in lesson
- Use of energy cube to teach concept of energy conversion and conservation

Teacher Survey 2022

(1) COURSE INFORMATION

Title of Session:	Using Multiple Representations to Teach Energy: An Alternative Conceptual Approach
Date(s) of Session:	21 April 22
Class Code *(if applicable)*:	
Conducted by *(delete accordingly)*:	MTT
Facilitator(s):	Boon Chien, Siew Lin

Your feedback will assist us in future planning.
No of forms =28 (F2F) / 12 (Online)

SQ Indicator
Usefulness (F2F): 3.60
Satisfaction (F2F): 3.58
Usefulness (Online): 3.53
Satisfaction (Online): 3.49
Weighted average: (3.60x28+3.58x28+3.52x12+3.49x12)/(40x2) = 3.57

(2) OVERALL FEEDBACK ON COURSE/WORKSHOP/SEMINAR/MASTER CLASS (F2F)
Please shade/tick the appropriate circle.

	Comments on Course/Workshop/Seminar/Master Class	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
1	The objectives were achieved.	o	o	7 (25%)	21 (75%)	3.69
2	The learning resources (e.g., videos, book chapters, websites, notes, lab protocols, etc.) supported me in my learning.	o	1 (1%)	9 (32%)	18 (67%)	3.56
3	I can apply the ideas/knowledge/skills learnt from the course/workshop/seminar/master class.	o	o	11 (39%)	17 (61%)	3.56
4	The presentation was clear.	o	o	9 (32%)	19 (68%)	3.59
5	The course/workshop/seminar/master class met my learning needs.	o	1 (1%)	9 (32%)	18 (67%)	3.50
6	I would recommend the course/workshop/seminar/master class to my colleagues.	o	o	9 (32%)	19 (68%)	3.63
7	The questions were adequately addressed.	o	o	9 (32%)	19 (68%)	3.63
8	The facilitator is skilful at facilitating the participants' learning.	o	o	8 (29%)	20 (71%)	3.66
9	The course / workshop / seminar/ master class helped me to reflect on my classroom practices.	o	o	11 (39%)	17 (61%)	3.56
10	The duration of the course/workshop/seminar/master class was sufficient to meet the objectives of the course/workshop/seminar/master class.	o	2 (6%)	8 (29%)	18 (67%)	3.50

(3) OVERALL FEEDBACK ON COURSE/WORKSHOP/SEMINAR/MASTER CLASS (Online)
Please shade/tick the appropriate circle.

	Comments on Course/Workshop/Seminar/Master Class	Strongly Disagree	Disagree	Agree	Strongly Agree	Mean
1	The objectives were achieved.	o	1 (8%)	7 (58%)	4 (33%)	3.60
2	The learning resources (e.g., videos, book chapters, websites, notes, lab protocols, etc.) supported me in my learning.	o	1 (8%)	7 (58%)	4 (33%)	3.50
3	I can apply the ideas/knowledge/skills learnt from the course/workshop/seminar/master class.	o	o	10 (83%)	2 (17%)	3.48
4	The presentation was clear.	o	1 (8%)	9 (75%)	2 (17%)	3.50
5	The course/workshop/seminar/master class met my learning needs.	o	1 (8%)	10 (83%)	1 (8%)	3.43
6	I would recommend the course/workshop/seminar/master class to my colleagues.	o	1 (8%)	9 (75%)	2 (17%)	3.50
7	The questions were adequately addressed.	o	1 (8%)	8 (67%)	3 (25%)	3.53
8	The facilitator is skilful at facilitating the participants' learning.	o	1 (8%)	8 (67%)	3 (25%)	3.55
9	The course / workshop / seminar/ master class helped me to reflect on my classroom practices.	o	o	9 (75%)	2 (25%)	3.50
10	The duration of the course/workshop/seminar/master class was sufficient to meet the objectives of the course/workshop/seminar/master class.		1 (8%)	9 (75%)	2 (17%)	3.43

Some useful idea(s) from the course/workshop/seminar/master class which I would like to apply: (F2F)

- Use of manipulative
- How to use LOL
- Use of energy charts and energy cubes to help students understand ideas of energy stores and energy transfer
- Energy cubes & LOL template
- The new idea of energy stores
- Very revolutionary ways of teaching energy.
- Using props like cubes to generate communications
- Teaching energies in terms of stores and the different modes of representation
- The scenario cards are innovating.
- The multiple representations for students to visualize and the LOL chart
- Terms used in energy stores and how energy is transferred in and out of the system.

11. Some useful idea(s) from the course/workshop/seminar/master class which I would like to apply: (Online)

- The idea of distinguishing between energy stores and transfers.
- The use of LOL and Energy cubes in my classes in future once I have the tools.
- The shift in terminology, the idea of transfer in and transfer out instead of transform/converted.
- How to teach this using an online platform that could possibly do it without the tools .
- Manipulative and scenario cards help to visualise the concept during introductory phase of the topic
- Introducing students to different energy representations in the form of energy stores
- Use of energy cubes and energy analysis
- The use of energy cubes combined with the Energy transfer cards
- I like the physical movement of cubes to represent the movement of energy
- the energy cubes is a good demonstration that energy is conserved.
- Different energy representations.

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