Using Challenge Based Learning to Teach the Fundamentals of Energy Transfer to High-School Math Teachers

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Abstract

This work is based on an effort to train high-school math teachers on how to incorporate Challenge Based Learning (CBL) into their classroom. A portion of the training was done by immersing them in a CBL project within the classroom which was titled "Engineering a Healthy Diet." CBL is based on identifying a Global Problem which for this project was the link between health and access to healthy food. The class instructor guided the teachers to see how the transfer of energy was linked to their Global Problem, and how the Engineering Design Process could be used to help better understand and possibly identify solutions to their problem. Two lessons resulted from their stated challenges: one on the units associated with power and energy, and a second lesson was on quantifying efficiency when transferring and storing energy. Activities were linked to these two lessons by using Microsoft Excel to model their Healthy Diet and see their equations at work. This paper discusses the project structure, the in-class activities, and the teachers' perception of the project.

Introduction

Challenge Based Learning (CBL) is an inductive pedagogy which allows students to identify a real-life problem that interests them and then learn what they need to know in order to solve the problem.[1-3] Information gained from doing assignments and projects can result in long term retention of the information and make the student feel like their school work has purpose. Math classes work well with CBL since the equations being taught are often universal to STEM disciplines. This allows for a large variety of topics to be covered under the umbrella of a single mathematical learning objective.

A flow chart describing the CBL pedagogy is provided in Figure 1. CBL is built around the Big Idea which ultimately will be linked to an academic standard or learning objective. Based on the Big Idea, students begin to formulate a set of Essential Questions. The Essential Questions are still very broad and just show that there are some important components of the Big Idea which are not fully understood. One of the Essential Questions is then selected and formulated into a Challenge which can be directly linked to a class unit. This is usually where the students are asked to build, design, test, and/or model a real world problem. To begin addressing the Challenge, the students are asked to form a set of Guiding Questions which will ultimately lead to specific units and activities to be performed in the classroom to help answer these Guiding Questions. The instructor works as a facilitator throughout this project and has to make sure the Challenge and Guiding Questions remain in line with the course unit and/or learning objectives.

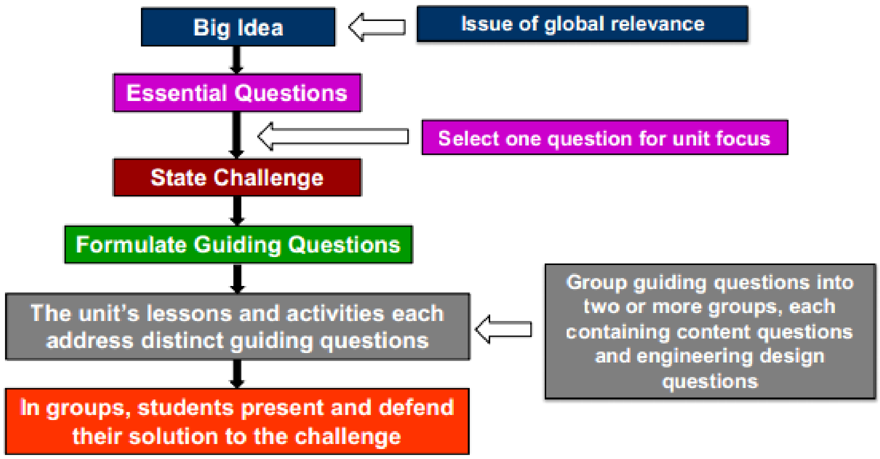

Figure 1. Flow Chart for implementing Challenge Based Learning[4]

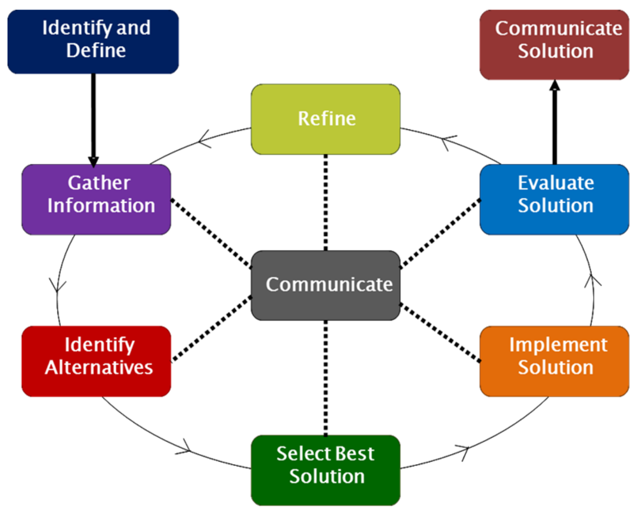

Figure 2. Engineering Design Process[4]

The Engineering Design Process (Figure 2) has been infused into the CBL pedagogy by becoming a major part of the unit's lessons and activities. For example, once the Guiding Questions have been presented, the units will often provide the students with the fundamental knowledge they need to begin to answer/solve the Guiding Questions. The Guiding Questions are part of the Identify/Define step in the EDP and the unit helps the students Gather Information. This can be done both in class and outside of class through independent research (similar to Homework). The students then communicate amongst each other what they were able to find on their own, which can help Identify Alternatives. The facilitator (class teacher) helps ensure through this discussion that they "Select the Best Solution" which must be solvable and related to the unit's lesson. The activities which sprout from the unit's lesson should be guided to help Implement and Evaluate Their Solution. This is concluded by the students communicating their results. At this point, the open-ended problems are never fully solved, and it is the instructor's job to help students identify ways to better improve their designed product. This will allow them to go through the Refine stage of the EDP. Going through the process again will allow the students to try and answer another Guiding Question.

Course Description

The CBL and EDP pedagogy was implemented in an Engineering Applications in Math class which was part of a summer math, science and engineering training program at the University of Cincinnati.[4] The objectives of the particular class were to get high-school teachers excited about math and engineering, to help teachers better understand the link between engineering and math, and to give teachers the resources they need to use similar math and engineering concepts in their classroom. A similar class was run the year before which had both middle-school and high-school teachers.[6] Since this class is built on the foundations of Mathematics, it was decided to split the cohort this year into a class with high-school math teachers and the rest of the cohort took a similar class but with less math rigor. This year's cohort consisted of eight high-school math teachers and one high-school science teacher. There was one high-school science teacher who was comfortable with the more complex math problems, so she also took the class.

The course met 3 days per week for 5 weeks during July 2014. The class met for 3 hours on Monday and Wednesday, and then there was a 1 hour class on Friday. Typically Friday would be used to wrap up the weeks work and introduce the fundamental concept to be used during the next week. There were two main CBL projects given during the 5 weeks. The first one was "Engineering a Healthy Diet" which will be described in detail below. The second project was used to train the teachers on ways to incorporate Engineering based activities into the CBL framework. This will not be discussed in the current paper.

Challenge Based Learning Project

The CBL project which will be discussed in detail was titled: "Engineering a Healthy Diet." The high-school teachers were the students of the class, so to avoid confusion; they will be referred to as the cohort. The cohort was presented with the following Big Idea: "A major impact on rising medical costs is the refusal of society to adhere to a healthy diet." After presenting the cohort with this idea, the instructor then let the class brainstorm about the issue for 10 minutes to form a list of Essential Questions. The instructor had each person give one Essential Question. The following are a few examples which were stated out loud and the instructor wrote them on the board:

Essential Questions (EQ):

EQ 1: What is the impact of there being fewer grocery stores and more fast food restaurants in urban neighborhoods?
EQ 2: How much does a calorie cost?

EQ 3: How do foods fit in popular diets and their associated costs?
EQ 4: How do you think the media impacts our eating decisions?
EQ 5: Is a more active person healthier than a non-active person?
EQ 6: Which is better to have the night before a soccer game, a meal high in protein or carbs?

The instructor then let the cohort know that they would address the first Essential Question by trying to understand the difference between home-cooked food and fast food. It was also stated that once this Essential Question was answered, it would be possible to begin to address or answer the other Essential Questions. The Guiding Questions were formulated by asking the cohort what they needed to better understand Essential Question #1. Below is a list of the Guiding Questions (GQ):

GQ 1: What is the conversion of food to energy?
GQ 2: Does the energy intake depend on food types?
GQ 3: How do different metabolisms impact the calories available for activities?

As the Guiding Questions began to be formulated, it became necessary to form a class unit which would discuss the link between Energy units and the Calorie. The Guiding Questions about types of foods (GQ 2) and Metabolism (GQ 3) added the perfect amount of complexity to require Microsoft Excel to be used as a Calorie calculator. This would naturally form another unit and a few more activities during the EDP Refine stage.

Through the Guiding Questions, the Challenge was finally stated which was "Design a Healthy Diet that obeys conservation of energy, is cost effective, and is practical." The instructor then proceeded to do a lesson on Energy Units, particularly the link between a Joule and a Calorie (kcal). The lesson began by having the cohort build a simple electrical generator. This was essentially an activity linked to the lesson. The materials included a piece of cardboard, 4 magnets, a nail, and wire. A schematic of a simple electrical generator is provided in Figure 3.

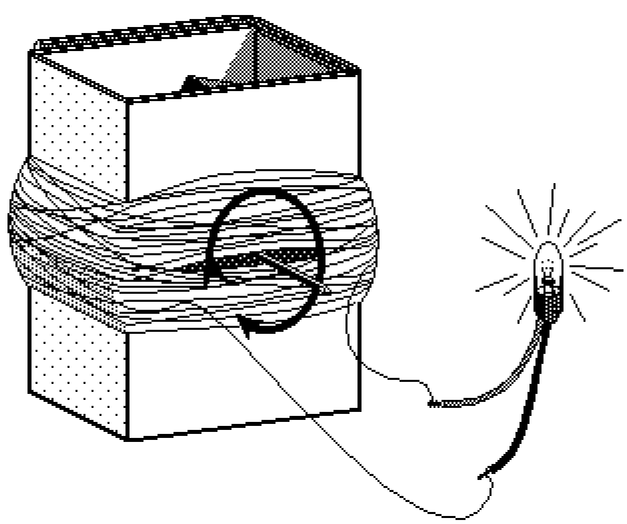

Figure 3. Simple electric generator.[7]

The instructor then asked how the units of Mechanical motion can be linked to the energy necessary to light a light bulb. It was then shown that 1 N-m equals 1 Joule. The instructor also reminded them that a N-m is a kg-$(m/s)^2$ which is the units for Kinetic Energy. By better understanding the continuity of energy units, they realized that if they do 10 N-m of work, it may provide 10 Joules of Energy to light a light bulb. This then turned into a lesson about efficiency. It was explained that efficiency is never 100% and it can be extremely low when going from one form of energy; Mechanical work, to another form, Electrical Energy for the generator. Finally, they realized with the Electrical Generator that if you spin the nail faster, the light bulb was more likely to light. This allowed a discussion into Power which was the ultimate link since it was Mechanical Power being converted to Electrical Power.

The lesson ended by describing the link between a Calorie and a Joule. It was pointed out that a Calorie (Cal) is really a kcalorie (kcal), and 1 kcal = 4.2 kJ. Having gone through the electrical generator exercise, it became easier for the cohort to understand that the units of energy were driving the numbers. Thus if a person wants to do something and the energy values for that activity are known, it becomes possible to determine how many Calories need to be consumed. Through the activity of building an Electrical Generator and the lesson explaining the different types of Units associated with Energy and Power, the cohort felt as if the first Guiding Question had been addressed and mostly answered.

Next, the cohort was asked to look at food labels and try to link information on the food label to energy. This is where the Guiding Question related to the "type of food" became important. Through a class discussion during the next meeting, it was a common thread through everyone's research that all food labels have fats, carbohydrates, and proteins. Some wanted to go in more depth with "good" and "bad" carbohydrates, but it was the instructor's job to keep them on track so their model did not get too complicated in the early stages. Everyone agreed on a general conversion between the mass of food and the energy available: 17 kJ for a gram of a Carbohydrate or a gram of Protein, and 37 kJ for a gram of fat. Thus, the food label provides how many grams are available for each type of food, and then you convert the grams to how much energy is provided by the food.

An activity was done using Microsoft Excel which allowed a user to input the masses for each type of food read from a food label into the Excel sheet and then convert the mass to energy. The first two bold boxes in Table 1 show a sample of this. As often is seen with CBL, the cohort went beyond the expectations of the instructor and even included the Thermic Effect (the third bold box) which is the energy necessary to break down the food. This offered a great discussion about conservation of energy and efficiency. After including the Thermic Effect, the total amount of energy was available based on how much was consumed. The cohort had answered the first two Guiding Questions. They understood the conversion of food to energy and they were able to see how different types of food impact the available energy. At the same time, the EDP was used because after Selecting a Best Solution, the cohort had "Implemented and Evaluated their Solution."

Food Mass		Energy Input		Thermic Effect		Energy-Thermic			
Carbs		17	kJ/gram	0.05	%	Carbs			
300	grams	5040	kJ	252	kJ	4788	kJ		
Fats		37	kJ/gram	0.05	%	Fats		Energy Sum	
65	grams	2100	kJ	105	kJ	1995	kJ	7728	kJ
Protein		17	kJ/gram	0.25	%	Protein			
50	grams	1260	kJ	315	kJ	945	kJ		

Table 1. Sample Excel Spreadsheet for tracking energy in food.

The third Guiding Question (How do different metabolisms impact the Calories available for activities?) was next addressed by asking the cohort to research the Metabolic Rates. This was the understanding that a human needs to take some of the food consumed and beat the heart, breathe, think, etc. This was considered a "Refine" stage in the EDP and would ultimately lead to improvements to the Calorie Calculator in Table 1. Everyone Gathered Information about metabolic rates and then a class discussion followed to "Identify Alternatives" and ultimately "Select the Best Solution" which was based on research performed in 2005.[6] The Resting Metabolic Rate (RMR) is dependent on age, height, weight and gender, and the calculations were complex enough that Microsoft Excel needed to be used. The instructor guided them through how to plot RMR using Excel as shown in Figure 4. On the abscissa is the Age of the person in years and this is for a given weight. The ordinate then provides the RMR over a 24 hour period based on their gender assuming the same age, weight, and height.

The cohort was then asked to create their own RMR based on what they knew about their weight and height for various ages. Assumptions had to be made which was a great link to Engineering since they had a plot to help quantify the impact of their assumptions. The value obtained in Figure 4 could then be used in the Calorie Calculator. Thus the RMR is subtracted from the Energy Sum to allow the user to know how much is available for activity. An example for this is shown in Table 2.

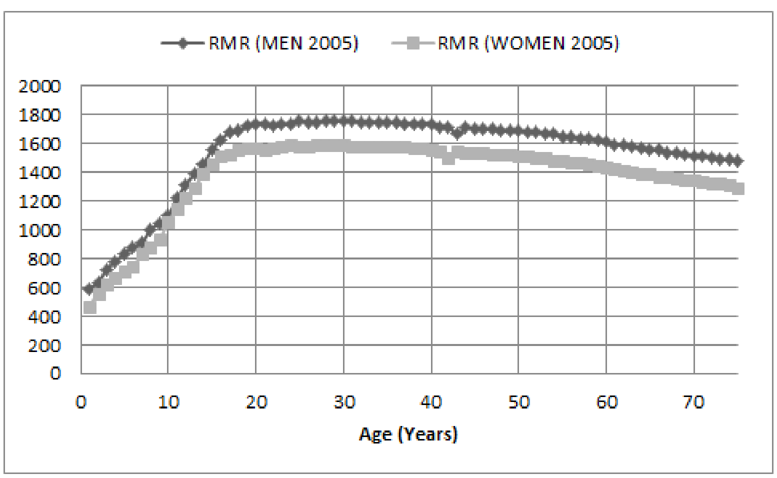

Figure 4. Sample RMR calculator

Food Mass	Energy Input	Thermic Effect	Energy-Thermic			
Carbs	17 kJ/gram	0.05 %	Carbs			
371 grams	6300 kJ	315 kJ	5985 kJ			
Fats	37 kJ/gram	0.05 %	Fats	Energy Sum	RMR	Available Activity
71 grams	2625 kJ	131.25 kJ	2493.75 kJ	9660 kJ	8065.289 kJ	1595 kJ
Protein	17 kJ/gram	0.25 %	Protein			
93 grams	1575 kJ	393.75 kJ	1181.25 kJ			

Table 2. Calculator for available activity

The cohort was asked to do one more "Refine" stage by using the calculator to answer one of the Essential Questions. Many of the high-school teachers seemed interested in trying to help their students understand the issue with fast food. Thus, what will be described below is how one group answered the first Essential Question. The impact was quantified by understanding the difference in available activity for someone who eats all fast food for one day versus someone who eats all their meals at home. Table 3 presents the findings from both calculators. It can be seen that a home-cooked meal provides much less Calories and would require someone to eat more food if they were active. On the other hand, the fast-food diet provides an excess of Calories (kJoules) which means the person is susceptible to gaining weight or required to an excess amount of physical activity. The group went on to quantify the difference in price between these two diets and came up with the fast food diet costing about $22 per person per day and the home cooked diet being $8.50 per person per day.

Daily Recommendations with Home Cooked Diet

Food Mass	Energy Input	Thermic Effect	Energy-Thermic			
Carbs	17 kJ/gram	0.05 %	Carbs			
277 grams	4704 kJ	235.2 kJ	4468.8 kJ			
Fats	37 kJ/gram	0.05 %	Fats	Energy Sum	RMR	Available Activity
18 grams	672 kJ	33.6 kJ	638.4 kJ	6115 kJ	6018.6 kJ	97 kJ
Protein	17 kJ/gram	0.25 %	Protein			
79 grams	1344 kJ	336 kJ	1008 kJ			

Daily Recommendations w Fast Food Diet

Food Mass	Energy Input	Thermic Effect	Energy-Thermic			
Carbs	17 kJ/gram	0.05 %	Carbs			
657 grams	11172 kJ	558.6 kJ	10613.4 kJ			
Fats	37 kJ/gram	0.05 %	Fats	Energy Sum	RMR	Available Activity
43 grams	1596 kJ	79.8 kJ	1516.2 kJ	14524 kJ	6018.6 kJ	8505 kJ
Protein	17 kJ/gram	0.25 %	Protein			
188 grams	3192 kJ	798 kJ	2394 kJ			

Table 3. Comparison between Home Cooked (top) and Fast Food (bottom) diet for a single day.

The project concluded with each group presenting their findings and particularly answering one of the Essential Questions. This is essentially the "Communicate Your Solution" for the EDP. This stage should never be left out because it really brings all the work back to the Big Idea and the Challenge. Through the work it could be seen that the path to a healthy diet is by understanding the impact of Calorie intake, Calorie Storage, and Calorie usage. The presentations allowed everyone to see the similarities in their analysis. This basically showed that they were all using the same math with slightly different applications. Each person was also asked to right a short report reflecting on how they used the EDP to get their solution.

Linking CBL Units to Academic Standards

For implementation of this CBL-EDP into the K-12 classroom, it is essential to link the unit's lessons and activities to Academic Standards. Below are 4 Common Core State Standards (CCSS[7]) in high-school Math which one teacher presented that are directly linked to this project. It is important for the teachers to see that what they are doing can be incorporated into their classroom, and projects will still ensure that they are able to meet the Academic standards.

CCSS.MATH.CONTENT.HSA.CED.A.2: Create equations in two or more variables to represent relationships between quantities; ***graph equations on coordinate axes with labels and scales***.

CCSS.MATH.CONTENT.HSF.BF.A.1: Write a function that describes a ***relationship between two quantities***.

CCSS.MATH.CONTENT.HSN.Q.A.1: ***Use units as a way to understand problems and to guide the solution of multi-step problems***; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

CCSS.MATH.CONTENT.HSN.Q.A.2: ***Define appropriate quantities*** for the purpose of descriptive modeling.

Course Feedback

With only 9 teachers were enrolled in the class, it is difficult to use the quantitative part of evaluations as a complete metric for the success of the CBL-EDP project. However, it could be seen that the cohort was very positive (a majority strongly agreed) on the following ABET questions:

(1) Work as a team member
(2) Identify, formulate, and solve engineering problems
(3) Understand the impact of engineering solutions in a broad context
(4) Use techniques, skills or modern engineering tools necessary for engineering practice.

All of these are directly linked to the outcomes of the CBL-EDP pedagogy. The cohort was paired as a team, but they also had to communicate to the group, so everyone could benefit from the findings of one team. The EDP was used to make guide the cohort as they were challenged with solving the complex problem related to a healthy diet. We were also putting our engineering solutions to work in a very broad context here. Finally, using the computer (inparticular Microsoft Excel) gave the cohort the sense that this was a problem being solved with modern technology. They understood without the computer, this could still be done but not to the extent that they were able to with the computer.

A second survey was given to the teachers to discuss the impact of CBL, the EDP, Engineering, and general questions about the course. The following survey questions received a 3.6 or higher out of 4 pts and all with a standard deviation of about 0.4:

- The sessions allowed for questions, answers, and discussions
- The course helped me understand how math and science knowledge is used by engineers to solve societal problems.
- The course helped me understand CBL through the use of a design challenge.

The cohort was most critical with the following survey questions:

- The course provided opportunities to enhance my oral communication.
- The students in my school will benefit from my experience in this course.
- The course helped broaden my understanding of the content.

The survey questions the cohort was more critical of had a score around 3.2/4.0 however the standard deviation was around 1 for all 3 questions. Thus some were still rating these high and others were rating them lower. The second question in this is the most important and still provides some challenges. During 2013 this course contained middle and high school teachers in one class. The problem there was that very few found value. Although this year's cohort (2014) was primarily high-school Math teachers (except 1), the majority taught Algebra 1 or 2 which this project could be used with. However, for the calculus teachers, this CBL project would have to be expanded to possibly include topics like optimizing a diet or discussing the time dependence of Calorie intake. Both of these topics could bring in derivatives and/or integration.

A couple of the comments in the course evaluations related to the "Engineering a Healthy Diet" project included:

- I plan to implement the ideas of dieting and food as it relates to engineering in my algebra 2 courses. The idea was very interactive and engaging.
- I really enjoyed the diet project plan. I feel students will be engaged in this activity and can learn about not only about math but science and health as well.
- I would like to include out diet design into a math class. I think this would spark the students' interests because it is something important in their everyday lives and it will attach mathematical concepts.

Conclusion

A Challenge Based Learning class module was introduced in a summer teacher training program. The course itself was structured under the umbrella of CBL and at the same time the students had to use the Engineering Design Process to design a healthy diet. Overall, the learning objectives were met from this project and it is believed the cohort will have long term retention of the information.

Acknowledgements

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