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Abstract. As part of an *APEC* educational project on the cross-cutting concept of energy, researchers and teachers from 6 countries spent 8 months designing, testing and implementing a pilot STEM public class with two schools from Chile and one from the US. One of the researchers taught a lesson from a school in Chile, with a live transmission to the other two schools via Skype. At the same time, the lesson was also broadcasted via videostreaming. In addition to live questions and answers, students used individual devices to answer four open-ended questions that were commented on by the reseacher as he received them. The experience demonstrated that Cross-Border Public Classes boost student engagement and represent a promising strategy for introducing a key 21st century skill: synchronous learning involving multiple teams across the world. It also revealed how Lesson Study and Public Classes integrated with ICT network technology can form a powerful learning ecosystem for regional development and social innovation.

Keywords: Future Education, STEM, Energy, Globalization, ICT, Lesson Study, Public Classes, Cross-Border

1 Introduction

According to the National Research Council [1], "Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges" (p. 1). However, current science, technology, engineering, and math (STEM) teaching and learning methods have not been adjusted to deal with these new challenges. The National Research Council calls for a new approach to K-12 science education. Another recent report from the National Research Council [2] underlines the fact that a major cross-cutting factor that has an impact on industry is the need for a solid foundation in STEM skills in many jobs; especially in sectors such as energy and mining. The report also shows that this need is growing on every level, as STEM principles are increasingly being applied in the workplace. A similar trend is occurring in agriculture. In its Review of the USDA Agriculture and Food Research Initiative, the National Research Council Committee [3] states that "the United Nations forecasts that global demand for food will need to grow by at least 70% by 2050 in order to meet the needs of a global population of 9.6 billion people" (p.vii). According to the Nobel laureate Philip Sharp [4], we need a new green revolution. Furthermore, nowadays most deaths worldwide are due to non-communicable diseases. Implementing dietary improvements can have profound effects on health, which means a whole new system of agriculture is needed to produce innovative and healthy products. Both of these trends are very important for the future of most countries; particularly those whose economies depend heavily on agriculture. However, unlike traditional agriculture, this new system will require a workforce that has a strong background in STEM. This places a challenge on educators to find new innovations for teaching and learning new content and practices.

1.1 Challenges of STEM Education

As highlighted by Honey, Pearson, and Schweingruber [5], one critical challenge in STEM education is integration. For example, the essence of the new biology is integration; not only between its many sub-disciplines, but also with physics, chemistry, computer science, engineering and mathematics. One key strategy is to emphasize the use of cross-cutting concepts such as energy and information. Another important strategy is to promote the use of argumentation with models in order to develop students' modeling skills, while integrating computational and mathematical tools. However, integration presents a significant challenge for traditional classroom practices.

The challenge of changing classroom practices is sizeable. Since as far back as Comenius' innovative proposal for science education in the XVII century, educational reformers have been trying to implement more student-driven, constructivist and active teaching strategies. However, several studies of classroom practice show that almost no change has taken place [6,7]. Moreover, the top-performing Organization for Economic Co-operation and Development (OECD) countries on the Programme for International Student Assessment (PISA) use more teacher-centered teaching practices in mathematics than other countries [8].

1.2 Lesson Study and Public Classes

Changing classroom practices is a sizeable challenge for teacher education and continuing professional development. One very powerful strategy involves Lesson Study and Public Classes [9]. Lesson Study was first developed in Japan over 140 years ago and is now being widely used throughout East Asia. Japanese teachers have also been teaching open and public classes for decades. In these classes, tens or even hundreds of teachers observe a lesson taught by a peer and analyze the lesson once it has finished. There are two very unique features of public classes. One is that it provides multiple perspectives: different teachers observe the class from their own angle and conceptual point of view. The other unique feature is the synchronicity of the viewing and actions that take place, as the teachers all perform the analysis simultaneously. This is very different to the observation of video recorded classes. Multiple perspectives and synchronicity are powerful levers that can help teachers improve their classroom practices. Furthermore, Japanese researchers had also developed a dialectic approach in the 1880s and a problem posing approach in the 1920s [9, 10]. These create a pedagogy that promotes critical thinking within mathematics education. However, according to Isoda [11], it was not popularized because teaching mathematics consistently using this approach requires a great deal of effort and was beyond most classroom teachers. Over the last 40 years, lesson study has been used to introduce the problem solving approach.

Lesson study and public classes [9] are powerful strategies of collaborative learning that reduce the isolation of teachers and classrooms. However, there are important restrictions that prevent them from unleashing their inherent potential. One major constraint is time [12]. Teachers have difficulty finding time in which they can get together for professional purposes. Teachers have to leave their classes and schools in order to be able to observe and analyze classes in other schools. This difficulty leads to only small teams of teachers participating in Lesson Study. In this paper, we describe an initial pilot experience in Cross-Border Lesson Study and Public Classes. This is an extension of lesson study and public classes, using the tools of Information and Communication Technologies (ICT), the Internet, social networks, video streaming and videoconferencing to design, test, and implement a cycle of collective improvement of a lesson, and then connect several classes at the same time and deliver a public class on another scale.

The mechanism of extending lesson study and public classes to a Cross-Border class has potential for facilitating changes in teacher practices. Teachers do not need to leave their school. It is a powerful Learning Ecosystem for teacher development and for teacher collaboration across schools from a large region that can include different countries. Moreover, it can also have a significant impact on students. The benefits of such a class are felt not only in terms of learning core concepts and competences, but also in terms of motivation and engagement. Students will enjoy additional benefits that are completely different to those provided by a traditional class. It will also be much more effective in preparing them for the challenges of the future world of work and being part of a global learning community. They will start to develop a new way of learning, where each class makes predictions, conducts experiments, and develops their modeling, reasoning and argumentation simultaneously with classes from other parts of the world. This could be a key component of education in the future. In both cases, as a Cross-Border Learning Ecosystem for teacher professional development and as a Cross-Border ecosystem for student learning, there is a need to research its impact. The goal of this project is to design and test a pilot cross-border ecosystem for Lesson Study and Public Class for teaching and learning core STEM concepts and practices.

2 Lesson Plan for Teaching Energy

The lesson that was designed forms part of the Asia-Pacific Economic Cooperation *(APEC) Cross-Border Lesson Study: Energy efficiency and Cross-Border Education* project. According to APEC, a forum of 21 countries, improving teaching and learning about energy efficiency is key for their economies. During the first meeting of the project at the APEC-Tsukuba International Conference X held on February 12th-15th, 2016, three central questions were proposed: 1) What is the major issue facing Energy in your economy?, 2) In relation to STEM, what reforms are taking place in your economy?, and 3) In relation to Lesson Study for Cross-Border, what possibilities do you have? These are key questions for Regional Development, and a useful strategy for learning about the different technological, social and environmental challenges faced by each country. A first demo class was implemented live involving a 9th grade Japanese class connected with a 9th grade Malaysian class using Skype for inspiring the development of cross-border lessons.

At the conference, several proposals for a lesson on Energy Efficiency and Cross-Border Education were presented by representatives from more than a dozen APEC countries. Among the teams from the Americas, the Mexican team proposed a lesson plan related to energy for middle school students, the Peruvian team proposed a lesson based on developing a generator for producing drinking water, the US team proposed a lesson plan where the cost of utilities were calculated, and the Chilean team proposed an energy lesson using a basic steam engine. After the meeting, the project directors suggested that the representatives from the Americas work together and prepare a joint lesson for the region. Based on the proposals from the US, Chilean, Mexican, and Peruvian representatives, lesson plan reviews and adjustments were discussed during Skype meetings throughout the first semester of 2016, together with a guest representative from Brazil. A diagram of the Lesson Plan cycle that lasted 8 months is shown in Figure 1.

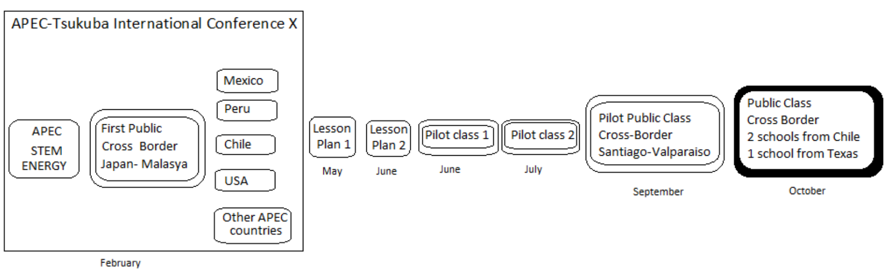

Fig. 1.. Diagram of the Lesson Study cycle from the APEC-Tsukuba International Conference (far left) up until the Public Cross-Border Class on October 4th, 2016 (far right).

Before the Conference, the attendees were asked to prepare a lesson plan. During the Conference, the cross-border project was explained and an initial Japan-Malaysia Cross-Border class was conducted. The different countries then presented their lesson plans. After the conference, a joint Lesson Plan was agreed on by the countries from the Americas. After a first joint effort to produce a lesson plan, and several revisions later, a second lesson plan was then designed. Subsequently, two pilot classes were then delivered in Chile. Finally, a pilot public class was taught, followed by a Cross-Border Public Class involving three different classes.

One initial idea was to integrate concepts of energy taken from physics and biology. For example, designing a lesson where students calculate their daily energy intake using tables showing the calorie content of different foods and comparing this with the amount of electrical energy consumed by different devices. Following this proposal, the researchers felt it would be interesting to add the task of estimating the energy spent when students are doing physical activity (running, swimming etc.). The researchers also had the idea of integrating the concept of energy with social development and the need to be more efficient with energy use in the future. Several observations and suggestions were made based on the initial plan. One recommendation was the need to teach units of energy, since they are not known by students. Another suggestion was to include questions that promote reasoning and argumentation. There was a concern regarding the use of White's law, even though this is a well-known formula that integrates Culture with Energy and Technology. However, the team felt that it could easily be misinterpreted. Another suggestion for estimating the energy spent was the need to carefully specify the amount of time spent doing the physical activity.

2.1 Pilots of Energy Lesson Plan

With this input, a first pilot lesson (pilot class 1) was held in June 2016 with a 7th grade class from a school in the La Pintana district of Santiago. During the lesson, the students used tablets to access the Internet to estimate the amount of energy spent during different physical activities. After this lesson was delivered, a group of local teachers suggested that the lesson would benefit from more active participation from the students. Instead of just searching for information about energy expenditure relating to different physical activities, they suggested actually doing the physical activities themselves. The idea was to design an experiment where the students have to jump or dance, since this could be very engaging for them. This suggestion was therefore included in the lesson plan.

Following this, a second lesson (pilot class 2) was then implemented and held on July 5th with another 7th grade class from the same school in La Pintana. Thirty students (15 girls and 15 boys, with an average age of 13.2 years) participated in a 90-minute session. The lesson was taught by one teacher, while two other teachers observed. The teacher asked the students which variables have an impact on the temperature of the air inside the classroom. In response to the question, the students suggested the body temperature of the people in the room, the size of the classroom, body motions, clothes, the thermal insulation of the room, the number of people and the temperature outside, among others. The students did an experiment, measuring the temperature increase under two conditions: condition 1 was at rest for 10 minutes; condition 2 was jumping for 10 minutes. From the increase in temperature they estimated the number of calories generated per student per minute in each case. This is a direct calorimetry-type measurement. A subsequent lesson was held a couple of weeks later following the winter vacations. During this second lesson, the students analyzed connections between energy and social development, making predictions for energy expenditure in the near future based on historical trends in the amount of energy captured per capita. The students then discussed the need to improve energy efficiency.

Based on this experience, a cross-border lesson was then prepared. Increasing the room temperature by jumping during a Chile-US cross-border public class was considered impractical for two reasons. Firstly, in a typical public class, held in a gym or theater, the increase in temperature is very slow because of the large volume of the room. Secondly, schools in the US have central heating and air conditioning systems that cannot easily be turned off. It was therefore considered more practical to use the data from the previous pilot class. Thus, an initial pilot cross-border lesson was held between a class from the school in La Pintana school and a school in Valparaiso, Chile. These two schools are located more than 100 Km apart. The pilot cross-border class was held over Skype on September 13th, 2016. The plan involved asking certain key questions to all of the students and having them respond online. We used ConectaIdeas, an online platform that we have used previously for interclass tournaments [13]. This way, the teacher is able to access the students' responses immediately, both those from the school at which he is present, as well as those from the remote school. Using the answers, the teacher can comment on them and refer to them during the session. The ConectaIdeas online STEM platform was used in order to ask students open-ended questions and have all of them submit their answers. Twenty five 8th grade students from the La Pintana school and 29 8th grade students from the Valparaiso school participated. Four teachers from Valparaiso were present at the Valparaiso school to act as observers, while another four teachers from Santiago were also present at the school in La Pintana. Four questions were posed online by the teacher. The first two questions were about content:

- Question 1: Which variables impacted the temperature of the room during the session that was reviewed? Explain your answer.
- Question 2: What is the volume of your classroom? Did you use exact measurements or did you estimate?

The other two questions were questions regarding the students' level of satisfaction. The students rated the class with an average score of 5.7 on a scale of satisfaction from 1 (lowest) to 7 (highest). The students commented that they enjoyed watching students from another school and doing a joint class. Some of the observers in Valparaiso expressed the need to repeat instructions given by the teacher in Santiago. Furthermore, the teacher from the Valparaiso school also expressed her dissatisfaction at not making the students do the jumping experiment. She and her students were expecting this activity to take place and were surprised that it was not included.

Following this experience, it was decided to reincorporate the jumping activity into the lesson plan for the following cross-border Class. However, given the time restrictions and the unpredictable conditions of the different rooms in which the

Cross-Border Public Classes would be taking place, such as very large rooms where the increase in temperature would be minimal or rooms with air conditioning that cannot be turned off, the new lesson plan did not contemplate having the students measure the temperature change. Instead, the jumping activity was going to be used in order to have a more active class, while synchronizing students from different schools, promoting social interaction, and encouraging students to think about the relationship between physical activity, heat, and energy. A revised lesson plan was then designed based on this experience (Appendix A). Several recommendations regarding the lesson plan were then received from researchers in the different APEC countries participating in the project.

2.2 Cross-Border Public Class on Energy

In this section, we describe the experience with a Cross-Border Public Class taught as part of the *APEC Cross-Border Lesson Study: Energy efficiency and Cross-Border Education* project. Figure 2 shows a diagram with the three classes from the three schools, the Public Class coordinator and several remote observers of the Cross-Border Public Class held on October 4th. Two classes were from schools in Chile (Santiago), while one was from a school in the US (Texas). The three classes participated simultaneously and were connected via Skype, as shown in Figure 3.

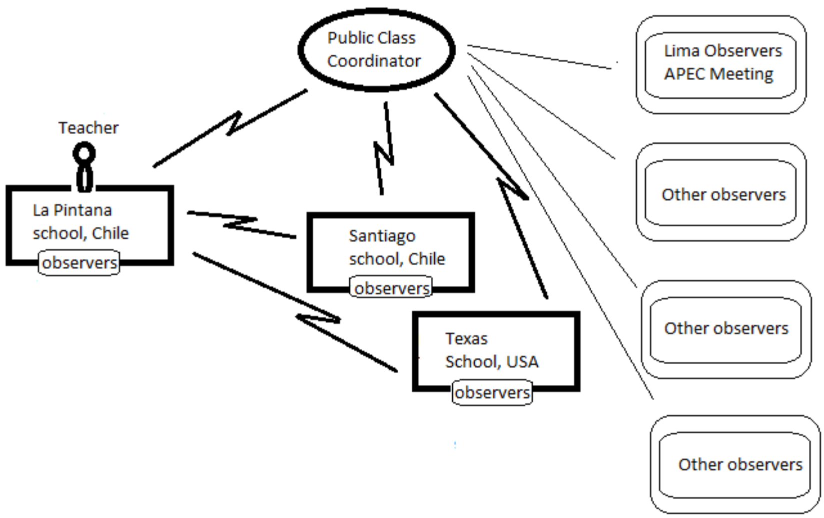

Fig. 2.. Diagram of the Cross-Border Public Class in Energy with 3 schools (two from Chile and one from Texas) connected synchronously. All of the students from each class participated by watching Skype and answering the researcher's questions using an online STEM platform. A Public Class coordinator, located at another site, video streamed footage from the three classrooms by using YouTube. Teachers and observers at an APEC meeting in Lima, as well as other remote observers, watched the video stream. The class was held on October 4th, 2016. It is the first Cross-Border Public Class that we know of where every student answered several questions online, and where the responses were received instantly by the teacher, as well as being reviewed and commented on.

The teaching methodology and technological infrastructure used for Cross-Border Public Classes is completely unique. In a Cross-Border Public Class, the challenge of classroom management is mind-blowing. The teacher needs to simultaneously handle several classes located in different parts of the world and to do so without losing personal contact with each individual student.

Fig. 3.. The teacher beating the drum and asking students to jump in rhythm with the beat. The two other participating schools are projected on the whiteboard and connected by using Skype. The students in these classes are also jumping.

In this particular lesson we included the use of ConectaIdeas, an online platform for asking open-ended questions. Therefore, in the Cross-Border Public Class the teacher maintains permanent contact with each student, both those in his classroom, as well as the students in the remote classrooms. Even though the class can be classified as a "whole class" lesson, where the teacher is constantly asking key questions to all of the students, he also receives written answers from each individual student. These answers are reviewed by the teacher, selected and immediately commented on. This teaching strategy is completely unprecedented in traditional classes or in technology-supported classes, as well as in teacher education and continuing professional development activities.

Fig. 4.. Screenshot of the Cross-Border Public Class video streamed via a YouTube channel. Three classes synchronized and jumping simultaneously: Left, school in Santiago; center, school in Texas; right, school in La Pintana.

The class was video streamed in real time (Figure 4) by the Public Class Coordinator, from a separate location. Therefore, observers from other schools or locations were able to follow the class on a YouTube channel. They also had online access to the students' anonymized written responses to the open ended questions.

3 Experimental Settings of the Final Public Class

Three schools participated in the final Public Class. However, the Internet connection with the Texas school experienced some difficulties 10 minutes into the session. Therefore, for the purpose of analyzing the students' responses, we only consider the information gathered from the two Chilean schools. The school in La Pintana is classified as low SES (lowest 5%) on the official Chilean Ministry of Education scale of Socio Economic groups. The students that participated in the Cross-Border Public Class were in 8^{th} grade. The class included 7 boys and 7 girls, with an average age of 14.6 years and a SD of 1.2. The school in Santiago is classified as medium SES on the Ministry of Education scale of Socio Economic groups. The students that participated in the Public Class were in 9^{th} grade. This class comprised 31 boys (it is an all-boys school), with an average age of 14.8 years and a SD of 0.5. They are the same age as the students from the school in La Pintana despite being one grade higher. This is due to the vulnerability of the students in the La Pintana school and therefore their tendency to repeat grades.

The teacher who led this class was a member of the research team. For the majority of the lesson he followed the initial lesson plan. He taught in Spanish and then repeated in English. However, several minutes were lost as there were problems with the sound quality at the school in Santiago at the beginning of the class. Therefore, the final portion of the lesson plan was not completed. The sound quality in Santiago was quite poor throughout the lesson. In this sense, the Public Class Coordinator, who managed the video streaming, helped by clarifying the main questions and giving instructions to the other schools both in Spanish and English. During the class, a model of a classroom was used, as well as several small, white cubes representing a cubic meter (Figure 5). This was a strategy to help understand and calculate the volume of the classroom.

Fig. 5.. On the left, the photo shows a wooden frame representing a classroom and two white cubes to represent two cubic meters of air. In the middle, the student shows two ping-pong balls representing two kilocalories. On the right, the teacher can be seen with an orange ping pong ball in his left hand, used to represent one Kcal, and a puppet on his right hand, used to represent a student.

During the cross-border class, four questions were posted on the ConectaIdeas platform by the teacher. They were written in Spanish and English.

- Question 1: What is energy and how much do you need per day?
- Question 2: What variables cause the room temperature to increase?

- Question 3: In one minute each student produces 2 Kcal. How many Kcal do they produce in a day? Explain.
- Question 4: From the graph (Figure 6) [14], explain why there is a big difference in the energy captured per capita between 15,000 years ago and nowadays.

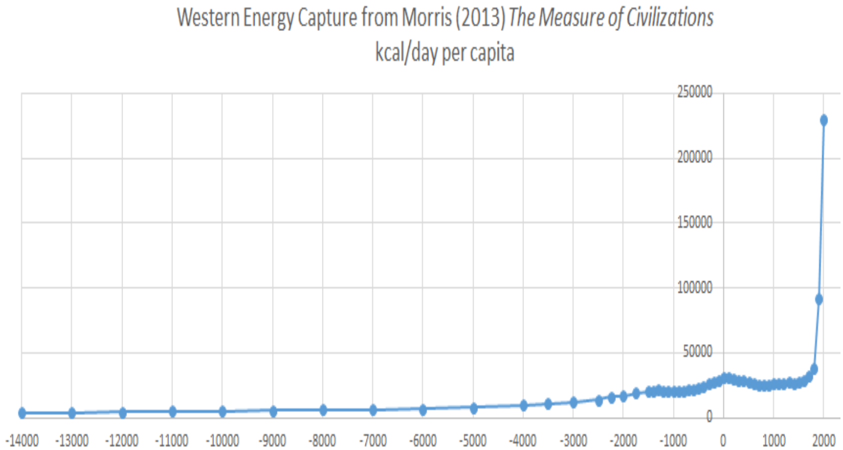

Fig. 6.. Energy captured in the West in Kcal per day per capita over the last 16,000 years. [11]

Forty-five students answered the first question; 44 the second question; 37 the third; and 39 students answered the fourth question. Each answer was recorded in a database. Following the cross-border lesson, 6 evaluators (3 teachers and 3 researchers) were sent the students' answers. These were anonymized and randomized so as not to reveal which school each student belonged to. The evaluators then graded the answers. For question 1, the evaluators gave two scores: one for the definition and the other for the estimation. For question 3, the evaluators also gave two scores: one for the calculation and the other for the explanation. For questions 2 and 4, as well as assessing each answer, the evaluators also counted the number of factors given in each answer. Students from the Texas School also received the questions but, given the communication problems they experienced, the students from this school answered on paper. Their answers were not received online and therefore were not commented on by the teacher. Thus, they are not included in this study.

A transcript of the class was then produced, including pictures that were taken during the class. Six teachers then classified each discourse according to three protocols and also wrote their comments. Two days after the class, a survey was administered on paper to the students from the school in La Pintana. The survey questions asked the students to describe what they liked and did not like about the class, as well as to rate the class with a score from 1 (lowest) to 7 (highest).

4 Results

The public class that was taught can be classified according to different frameworks. Firstly, we present some very basic statistics from the class. During the class, the researcher posed 105 questions, while the students posed 4 questions. The researcher's questions represented 32% of his discourse, when calculating the number of words in the questions as a percentage of the total number of words used in the teacher's discourse. Interestingly, the number of words spoken by the students accounts for just 9 % of the total number of words registered for the lesson. However, if we also count the number of words in the students' written answers, then the percentages change drastically. In this case, the number of words from the students accounts for 66% of the number of words used in the lesson (both spoken and written). This means that by using the Learning Ecosystem provided by the online STEM platform the students are much more active and their participation statistics change radically, with the level of active student participation skyrocketing.

A preliminary analysis was also conducted by using the students' written responses. This analysis mainly shows the promising potential of Cross-Border Public Classes, where students respond to open-ended questions synchronously using an online platform. This is a very innovative mix, since it helps have all students actively participate in an extended public class, where several classes are present at the same time either physically or virtually.

4.1 Counting the Words in Student Responses

Besides this important proof of concept, an initial analysis reveals interesting patterns within the answers given by the students from the two schools. By counting the words in the students' responses, we found out that there were certain patterns related to the length of the answers that were given. Students from the school in Santiago gave longer answers to questions 2 and 3. Question 3 is a calculation question and is self-contained. It did not require the students to be able to hear the teacher well. The difference in these questions can be explained by the fact that the students in Santiago were one grade higher and that the school traditionally outperforms the La Pintana school on standardized tests.

The answer to the third question was significantly shorter for students from both schools. This is probably due to the fact that this is a calculation question. Although the question also asks for an explanation, in most cases the students only provided a brief explanation.

4.2 Analyzing Key Terms in Student Responses

Next, we analyzed certain key terms that were present in the students' responses. One of the teachers in our research team searched for the key words manually. For each question, he selected six key concepts from the list of words used most frequently in the students' responses. Then, for each of these key concepts, the proportion of students that used this word in their answers was calculated.

Interestingly, some of these key concepts were used much more frequently in one school than in the other.

- In answers to question 1, the following concepts were used much more frequently by the students from the school in La Pintana: “heat”, “movement”, “matter”, and ”work”. This may be due to the fact that a higher proportion of the students in La Pintana copied and pasted their answers from the Internet than the students in Santiago.
- In answers to question 2, the word “ventilation” was used much more frequently by the students in La Pintana. This may be an effect of the discussion held with the teacher. On the other hand, the term “weather” was used much more frequently by the students in Santiago.
- In answers to question 3, the students in La Pintana used the word “hour” much more frequently. This may be due to the fact that the teacher held a discussion with the students in order to help them think in terms of hours before going for daily rates. This discussion was not audible to the students in Santiago.
- In answers to question 4, the students in La Pintana used the words “energy”, “buildings” and “houses” more frequently. The students in Santiago preferred the words “years” and “atmosphere”. This difference in frequency confirms the prediction made in the lesson plan that it was going to be difficult for the students to realize the “accumulated energy in cultural objects like buildings, highways, and bridges”. Since this was the subject of a discussion led by the teacher in La Pintana, and was not audible to the students in Santiago, the students in La Pintana included these factors in their responses, while the students in Santiago did not.

Given the poor sound quality over the Skype transmission, there was a significant difference in the level of instruction received by the two classes. The students in Santiago did not receive clear explanations and did not participate in the dialog-based section of the class. However, the students in Santiago are one grade higher, but just two and a half months older, and attend a selective school, whereas the school in La Pintana mostly caters to at-risk students. These differences can probably explain the different patterns in the words that were used. Another key component of the analysis is the integration of core concepts. In this sense, there are clear differences between the schools. For each pair of key concepts, we calculated the proportion of students that used them in their responses. These are called interconnectivity matrices.

- In question 1, the students in La Pintana integrated the term “energy” with the terms “heat”, “movement”, and “work”. Again, this may be the result of the students having copy-pasted definitions taken from the Internet.
- In question 4, the students in La Pintana integrated the term “energy” with the terms “buildings”, “houses” and “hours” , while the students in Santiago used a combination of “energy” and “years”.

Therefore, the matrices reveal interesting patterns in how the students integrate core energy concepts, as well as the impact of the teacher-student argumentation. However, the amount of data is very limited and larger samples would be needed in order to make more robust conclusions.

4.3 Scoring of Student Responses

The analysis described above is very basic and based on counting words or pairs of words. A different analysis is based on the assessment of the answers. Six evaluators (3 teachers and 3 researchers) graded the answers. The students' responses were anonymized so that the evaluators would not know their names, gender or school. The responses to question 1 were given two scores: one for the definition of energy and another for the estimation of the amount of energy needed by the student per day. The responses to question 2 were only given one score. However, the evaluators also had to count the number of variables named by each student. The responses to question 3 were given two scores: one score for the calculation and one for the explanation. Finally, the responses to question 4 were given one score, but again the evaluators had to count the number of factors named by each student.

For Question 1, the students from the two schools received similar scores for both the definition of energy and the estimation of the amount of energy needed. For Question 2, the students in La Pintana received a higher average score. This is probably because the students in La Pintana were more exposed to the teacher's discourse, as well as to the argumentation and interaction that took place in the class. The students in Santiago, on the other hand, could not hear the teacher well. The students in Santiago did better in their responses to Question 3, both in terms of the calculation as well as the explanation. This is probably due to the fact that with this question there was no need to have been able to hear the teacher and the argumentation. In this sense, the students in Santiago had the advantage of being one grade higher and coming from a selective school. Finally, the students in La Pintana did better on Question 4. Again, this is probably due to their exposure to the teacher's discourse. All of these differences are statistically significant. From these assessments we can conclude that the exposure to the teacher's discourse had a significant impact on performance. The remote school is almost like a control group that received very poor instruction.

5 Discussion

Two important questions are which components from the key cross-cutting concept of energy did the students learn about and how does this lesson compare to other possible lessons. The difficulty with the last question is that there is no traditional lesson that addresses the concept of energy connecting the physics concepts of energy and heat, the chemical notion of calorie, the biological notion of metabolism, the economic notion of energy sources, the social development notion of captured energy per capita, and the historical notion of trends of captured energy per capita in recent millenniums and its environmental impact. Unfortunately, there is no traditional lesson that achieves this level of integration, and this is why APEC funds an innovative project starting in elementary and high school education, looking at the integration of energy-related concepts and the related concept of energy efficiency. This means that there is no traditional lesson to use as a control lesson in order to compare learning and motivational outcomes.

However, integrating these different componentsof energy is a critical skill that new curricula are looking to develop [5]. One possibility, therefore, is to compare the proposed lesson with other options for teaching these integrated notions. For example, instead of jumping and measuring the increase in the temperature of the classroom, a lesson can propose reviewing and analyzing energy information from public databases that are available on the web. The multinational team considered and tested this option as part of the development of the class and the Lesson Study cycle. As mentioned previously, students were not as engaged in this class. The students from Valparaiso rated the class with an average score of 5.7 on a scale from 1 (lowest) to 7 (highest), whereas the students in La Pintana rated the final Public class, including the jumping activty, with an average score of 6.6 on the same scale. It is very important to underline that this high score cannot be due to the use of tablets or other ICT. For the last two years, students from the school in La Pintana school have been attending 90 minutes sessions every week, where they use tablets and the ConectaIdea platform. Thus, tablets are not a novelty for them. The students in this school are used to writing their answers on tablets in order to respond to open questions posed by the teacher in real time. Thus, the high level of satisfaction most likely comes from the activity itself and the cross-border nature of it. When asked what they enjoyed about the class, some of the comments from the students in La Pintana included “I learned a lot”, “I liked it when we jumped”, and “I liked seeing others jump”. The main aspect that was highlighted in their responses to what they did not like about the class was the poor Internet connection, although this was not due to Internet in their school but in the other schools. On the contrary, when the students from Valparaiso discovered that they had missed out on the jumping activity, they expressed their disappointment.

Another goal of the cross-border lesson that was designed was to provide the teacher with an online tool that gave them an estimation in real time of the students’ participation and learning. This is particularly important since most of the students in a cross-border lesson are located in remote classrooms and therefore it is very difficult for the teacher to watch them and assess their participation and understanding. The lesson that was designed included four open questions that students had to answer on their tablets. However, given the time restrictions it is not always possible to analyze in detail all of the responses. One quick and simple measure that can be obtained is the length of the students’ written answers to the open questions. The question is whether there is any relationship between the word count for the students’ responses and the scores that were obtained through a detailed correction process conducted with sufficient time. In order to conduct this analysis, the students’ responses were assessed and scored by 6 evaluators after the class. These scores were then normalized and analyzed. For question 1, there is a positive correlation between the length of the response and the average score. This is true for the score given for the definition of energy, as well as the score given for the estimation of the amount of energy required per day. For each extra word used in the response there is an increase of 0.05 standard deviations in the score. The R^2 is 0.30, which means that 30% of the variance in the scores is explained by the length of the responses. For question 2, the correlation between the length of the response and the score that was given is very weak. For question 3, however, the score given for the explanation is strongly correlated with the number of words in the response. For each extra word used in the response, the score increases by 0.06 standard deviations, while 51% of the variance in the scores is explained by the length of the responses. This is expected, because the evaluators probably scored implicitly based on the length of the explanation. For question 4, the score is also correlated with the length of the response, where 25% of the variance in the scores is explained by the length of the responses.

Another strategy that is quick and simple to implement is to count the number of occurrences of pairs of key words. The use of pairs of key words also has some effect on the scores. This is true for the score given for the explanation section of question 3. An extra pair of key words used in a response increases the score by 0.42 standard deviations, where 35% of the variance in the scores is explained by the number of pairs of key words.

Another strategy that is also quick and simple to implement is to count the number of variables named in the response to question 2. In this sense, an increase of one standard deviation in the number of variables named increases the score by 0.76 standard deviations (Figure 7). R^2 is 0.58 and, therefore, 58% of the variance in the scores is explained by the number of variables named in the response.

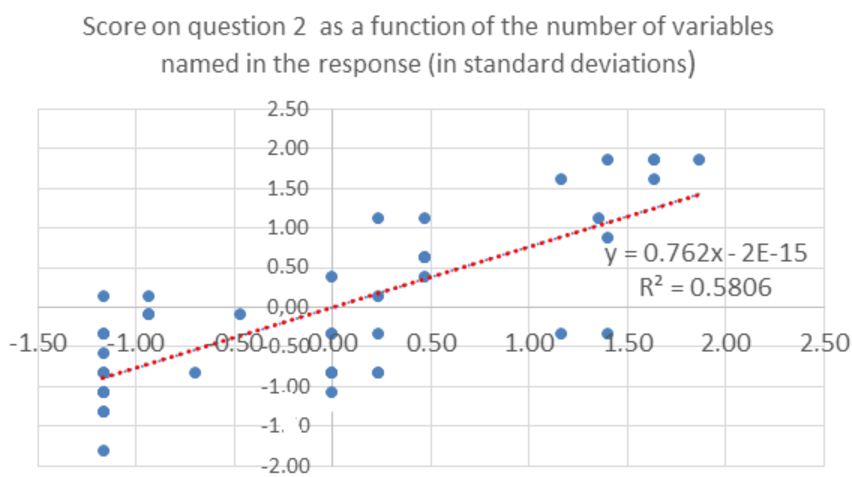

Fig. 7.. Correlation between score on question 2 and number of variables named in the response

The number of factors named in the responses given to question 4 also has an impact on the grades. An increase of one standard deviation in the number of variables named increases the grade by 0.59 standard deviations, with an R^2 of 0.35. Therefore, 35% of the variance in the grades is explained by the number of factors named in the responses given to question 4.

It is interesting to compare the predictability of these variables with the students' grade point average (GPA). GPA is normally expected to be a good predictor of the score obtained on a new test. In this particular lesson, GPA explains much less of the variance in the scores given for this question than the aforementioned factors. For question 1, GPA explains less than 1% for both sections of the question. Similar results are found for questions 2 and 3. It is only in question 4 that GPA has an R^2

above 0.01. For this particular question, GPA explains 13% of the variance in the scores that were given. This is a very interesting finding that requires further study and should be replicated with larger samples. One reason could be that answering open-ended questions requires different skills than the mathematics and science skills usually measured on regular school tests. Another reason could be that the lesson managed to engage students that are not normally attracted to traditional mathematics and science classes. This may be due to the effect of social facilitation. In [12] we found a similar effect on students with a below-average GPA. The social facilitation mechanism activated in lessons involving synchronous activities between schools engages these students more than a traditional class. Therefore, their performance improves significantly, reducing the gap between students with a below-average GPA and those with an above-average GPA.

These patterns are very promising tools that could be used in the future to develop smart teaching and learning ecosystems that can automatically detect interesting answers. They could also be used as a mechanism for showing the teacher a list of the responses based on an automatically estimated score. These features would facilitate the teacher's job of searching and selecting responses while teaching the class.

5.1 Suggestions for Revising the Cross-Border Lesson Plan

A Cross-Border Lesson Study session was conducted by teachers and researchers from several participating countries following the Public Class. The study was based on the transcript of the Cross-Border Class. Some of the suggestions received included the following:

- Given that the concept of "energy" is central and transversal to many STEM disciplines, it is worth exploring alternative methods that will allow the students to have a deeper understanding of the topic. One suggestion is to use the money metaphor for energy. Money, like energy, is not created; it is simply somehow transformed.
- When the teacher explained that the amount of heat required to increase the temperature of one cubic meter of air was one quarter of the amount required for heating water, he could have invited the students to conjecture instead of simply stating the fact. This is an opportunity to reflect on energy, heat, and how heat behaves differently in air and water.
- The notion of transforming energy is very important. Since the notion of energy is very abstract, perhaps there are other ways to help visualize this concept.
- Another suggestion is to spend more time explaining the notion of captured energy. This is something that requires a shift in thinking. Students are used to spending energy and not thinking in terms of the amount of energy captured from food and other sources.
- It would be important to dedicate some time to analyzing and discussing the difference between heat and temperature, and to be more careful about the transition from water to air, and the specific heat of air.
- The equilibrium notion was not mentioned, nor the loss of temperature due to poor insulation. Both are important points in the argumentation, but the teacher

consciously chose not to mention them due to time constraints. However, this is a point that should be carefully discussed in a future lesson.

- The importance of insulation should be discussed in more detail, as well as the notions of "space" and "volume" and their relationship. The temperature at different heights should also be considered, in addition to the solar origin of energy.
- There should be a more careful explanation that the wooden frame is a reduced-size model of the room. It seems that not all of the students understood this was a scale model.
- The first part is about energy concepts in Physics, Chemistry and Biology, whereas the second is related to History and Social Development. There should be a smoother integration between the first part of the class and the second part.

5.2 Classifying STEM Teaching Practices

A group of researchers and teachers also classified the events in the class according to three protocols for STEM teaching practices. Each protocol provides a common set of statements or codes to which the observers must respond. One such protocol is a framework for describing practical work in science classes [15]. It looks at whether the section of the class is more related to ideas, to objects, linking the two domains objects/ideas, or to other elements. According to [15] one cognitive challenge is linking objects to ideas, and thus the teacher should incorporate explicit strategies to help students make such links. As seen in the top graph in Figure 8, there are two moments where objects were used: in the first moment a wooden frame was used to represent the classroom and a white cube was used to represent a cubic meter, while in the second moment an orange ping-pong ball was used to represent a kilocalorie and a puppet to represent a student. Even though most students did not have the opportunity to work with these objects, we classified the teacher's actions based on his use of the objects.

Another of the protocols used was COPUS [16]. This protocol was specifically developed for describing college STEM classes, responding to the need for measuring teaching effectiveness beyond student evaluations [17]. This protocol was adapted for use with middle school students for the present study. One such adaptation was to change the element "Asking a clicker question" to "Asking an online question". This was because clicker questions are multiple choice, while the questions used in the cross-border class were open-ended questions. The protocol classifies the teacher's actions into several different categories. As seen in the bottom graph in Figure 8, four online, open-ended questions were posed. In total, teacher questions represent more than 50% of the teaching. Just over 32% of the words in the teacher's discourse belonged to questions. This difference may be due to the fact that while word classification is objective, the evaluators may have considered sections of the class to relate to questions being asked when in fact the teacher was simply clarifying concepts. The evaluators may also have classified the time that lapsed between questions as a teacher-led question.

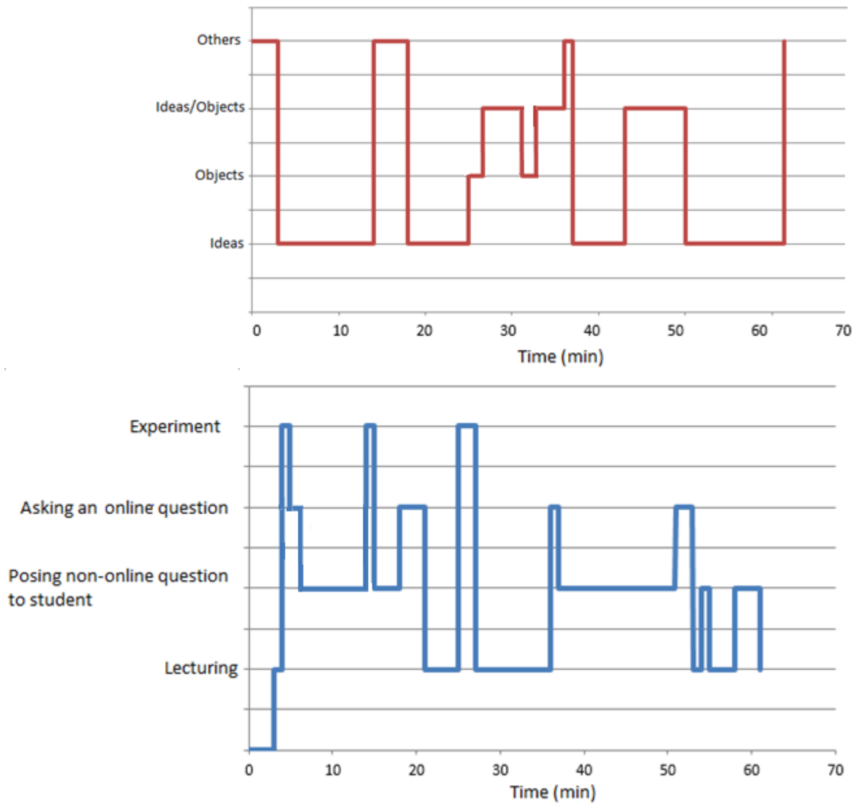

Fig. 8.. Evolution of the use of ideas or objects by the teacher during the session, and evolution of the COPUS categories used by the teacher during the session.

The third protocol is one designed to describe how learning processes are mediated by talk orchestrated by the teacher in whole-class teaching sessions [18]. It is a framework for analyzing classroom communication and consists of four categories generated from the combination of two dimensions: interactive/noninteractive and authoritative/dialogic. The evaluators classified the class as mainly interactive and dialogic. This means that they considered the class to be highly interactive, with several teacher-student dialogs dominating the class. However, the dialogs were restricted to the students at the school in La Pintana.

Following this experience, we are able to make certain recommendations for future Cross-Border Public Classes:

- Make sure to have a good Internet connection. Instead of Skype, there are other videoconferencing services that are more reliable and with better quality. Some of them are not free, such as Zoom.
- Make sure to have a good microphone for the teacher.
- Make sure to have a good sound system in each class.

- Include a robotic system to automatically control the camera that follows the teacher. Such systems have a microphone for the teacher that also shows the camera where the teacher is. For example, Swivl is a classroom video robot that helps capture dialog in classrooms.
- Plan an active role for the teachers in the remote classrooms. This will require more coordination and a careful and more detailed lesson plan. However, it can also improve the learning experience for the remote students. This is particularly important when the Internet connection fails or is unstable.
- Have objects available for all of the students in each of the participating classrooms. This would allow all of the students to use the wooden frame as a representation of the classroom and to use small cubes to calculate the volume.

6 Conclusions

According to [19], research on in-service teacher learning is in its infancy, but there is strong evidence that teachers' individual, professional learning can be positively influenced by being involved in Lesson Study. However, given the practical difficulties of coordinating study meetings with teachers from different schools and regions and, moreover, the critical time and travel restrictions to teaching classes in those schools with the presence of teachers from the other schools, the mix of Cross-Border Lesson Study and Public Classes with the support of an appropriate ICT-based ecosystem is an innovative and powerful strategy for collectively designing and improving lessons. It is also a particularly powerful strategy for strengthening networks between teachers from different schools, and for developing regional and international connections. It is a powerful tool for integrating students into a globalized world, as well as a promising strategy for introducing students from more underprivileged areas to networks of students with more resources and social connections. Finally, Cross-Border Public Classes are also a tool that use social facilitation mechanisms to boost student motivation.

Cross-Border Public Classes and Lesson Study undoubtedly represent a new form of teacher education and teacher professional development. It is a further development of cross-border activities that have been developed over the last few decades. For example, [20, 21] illustrate a Cross-Border Lesson Study using an internet-based Bulletin Board Systems (BBS) between pairs/classes such as Japanese and Australian schools. It reports a significant cultural impact on students, awakening their cultural perspectives on the contents and developing their hermeneutic attitude for collaboration. In the APEC project reported in this paper there are several new ICT-based features. There is a live video transmission and an augmented synchronicity of students, through jumping and answering live, as well as online, written open questions. Cross-Border Public Classes and Lesson Study are also a further development of massive team games across classrooms [22, 23]. In these activities tens of schools play synchronized games with one or two teams per classroom, where each team is formed by a dozen students. Other cross-border based games with tens of whole classrooms from different schools synchronizedly playing STEM games are also reported in [13]. What is additionally new in the APEC project is the cross-border design and the Lesson Study cycle that is being collectively developed across 8 months by a multinational team of researchers and teachers. Another important difference is that in the Public Class there are physical STEM experiments. These are performed by all of the students and at the same time. This is a different kind of synchronized activity than those on multiplayer games. In this case, the nature of the communication between students is very different than in games.

The innovation of the Cross-Border Lesson Study and Public class experienced in this APEC project resides in the increasingly active participation of all students and the synchronization of digital and physical activities. These components help to augment the students' engagement and active participation.

On the other hand, for teachers, there are several important innovations:

- As with any public class, this is not a lecture or theoretical class for teacher development. It is the process of designing and studying a real lesson, with students in-situ doing what was planned. It is critical to note that Cross-Border Lesson Study and Public Classes retain the distinctive practical feature of Lesson Study and Public Classes that have been developed and improved in Japan and the rest of Asia for over a century.
- It does not require teachers to leave their school. This is on-site and on-the-job training. This feature facilitates its implementation since there is no need to look for replacement teachers when the teachers attend the training. There is also no need to ask teachers to work overtime.
- Several classes can participate and not just one class, which is the case in a typical Public Class. This is a powerful mechanism that multiplies productivity and effectiveness.
- Each teacher observes the impact on his/her own students. This is completely new and very different to traditional Public Classes, where teachers observe the impact on students with whom they are unfamiliar.
- Access to each student's written responses allows for the use of highly innovative and promising technological algorithms to measure integration through text mining, such as the "Interconnectivity Matrices" proposed by Helaakosky & Viiri [24]. In our experience on October 4th, we were able to detect important patterns in the responses from the two schools. These patterns are otherwise very difficult to detect in both traditional and public classes.
- A real, online, synchronous teacher community is created. The synchronicity generates a much stronger network, with more in-depth practical knowledge and instant feedback.
- Productivity is much higher than with typical training. Several teachers participate with their classes in the creation and study of lessons, during regular class time.

There are also very important and unique benefits for the students. The Lesson Study cycle for the APEC project and the pilot classes undoubtedly had an impact on the students. In the particular case of the Cross-Border Public class on October 4th, the students who participated had the opportunity to reflect and put into practice some of the following core STEM concepts and practices:

- Physics: heat, temperature. Biology: nutrition, metabolism. Chemistry: gases, direct calorimetry.

- Cross-cutting science concepts: energy, equilibrium.
- Scientific practices: data gathering and interpretation, controlled experiments.
- Math: graphs, proportional reasoning, geometry, mathematical modeling.
- Engineering practices: strategies for calculating the energy efficiency of buildings.
- Technology: the use of instruments and ICT to type and share explanations.
- Social studies: economic and social development, historical trends and predictions.
- Students have the opportunity to connect core concepts with physical activity like jumping. According to [25] an emerging field of research shows that physical activity can benefit cognitive functions and academic achievements in children. In this Lesson the physical activity was strictly integrated into the core concepts to be learned, and was finally integrated due to the motivational impact on students. However, a special and larger randomized controlled study is required in order to measure its effect on learning.

Furthermore, the cross-border nature of the class should bring with it several other benefits, such as:

- Access to innovative lessons that are being designed by teams of teachers.
- Social facilitation effects [13], which boost engagement and collaborative learning.
- Access to knowledge of other cultures and inclusion in networks of peers from other schools.
- Social wealth. According to [26], wealth has always been social, and one of the critical challenges of the digital era will be how to share social wealth.

According to [27] schools are natural candidates for becoming drivers of social innovation and regional development. If we imagine the future of education, Cross-Border Lesson Study and Public Classes could well be at the center of this innovation.

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Appendix A – Cross-Border Energy Lesson Plan

Goals for the teacher: give students the opportunity to reflect on the cross-cutting concept of energy, and its connections to physics, biology, math & social development. Connect with students from other schools and countries to reflect together on the need to improve energy efficiency.

Goals for the students: recognize the cross-cutting nature of energy, its relationship to physics, biology and social development, and recognize the need to work together to improve energy efficiency.

Mission: to help achieve social development across the world, but with greater energy efficiency.

Materials: Thermometer, drum, graphs, platform for submitting responses

Time	Teacher activity	Student activity/response
00-15 min	1st stage: Meet each other; answer the first question using the system • Teacher asks what is energy and how much do you need per day • Teacher selects some answers from the platform and comments on them	**Anticipated student response:** students describe electric and fossil fuel energy
15-30 min	2nd stage: The concept of energy for raising the temperature. • Students jump to the rhythm of a drum • Teacher asks students to name variables that cause the room temperature to increase • Teacher compares answers and comments on them	**Anticipated student response:** Students name number of students, size of room, equipment, but probably not insulation.
30-45 min	3rd stage: Measure energy: calories: • Teacher shows graph of temperature increase and explains concept of calories, connects physics with biology, accumulation-loss of temperature and equilibrium, shows graph of temperature decay, and explains how to estimate calories spent per student • Students estimate volume and mass of air in the classroom, estimate calories to maintain the equilibrium, and estimate calories per student • Teacher selects some answers and comments on them	**Anticipated student response:** students estimate volume and discuss how to convert it to mass, and then to calories. They struggle with the idea of equilibrium.
45-60 min	4th stage: Energy captured throughout history • Teacher shows graph of energy captured per day per capita since 15,000 BCE • Teacher asks to explain the source of extra energy captured today • Teacher selects some answers and comments on them	**Anticipated student response:** students´ answers include transportation, electricity bills, but they don´t include energy accumulated in objects and buildings (to build such things).
60-80 min	5th stage: Energy and social development and need to be	**Anticipated student**

	efficient • Teacher shows energy captured (calories) per day per capita in different countries • Teacher asks how to estimate how much more energy is needed to have all the world living like in the US, and explain the consequences • Teacher selects some answers and comments on them • Teacher sends a survey question: Which aspects of the Cross-Border lesson were most interesting?	**response:** students understand the large amount of extra energy that is needed and discuss the implications for global warming.