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The Rare Earth Elements (Lanthanides) and Their Significant Roles in Society: Role-playing Learning Activity for STEM Education

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ABSTRACT

In this paper, we describe a role-playing learning activity in which groups of students work together to develop and present convincing arguments to support or oppose a government plan to promote the mining of lanthanides (rare earth elements) in the USA by giving financial incentives to the mining companies and easing the regulations and environmental restrictions for mining these elements. Students research the rare earth elements, and the short-term and the long-term effects of mining them in the USA on the economy, scientific and technological advances, the environment and the overall well-being of society. This is an issue that will likely be theirs to solve as the next generation of scientists, researchers, industry and business leaders, politicians and policy makers and informed citizens. Students additionally benefit by working in teams, presenting their own research and opinions, and learning to take on the roles of others, thus improving their social skills and academic performance. We include rubrics for assessment of the activity and for individual students' degree of involvement, and we provide suggested questions and research topics for both pre-activity and follow-up use.

Keywords: Student success, role-play, rare earth element, geoscience, STEM education, active learning.

Introduction:

In our increasingly commodity-conscious society, not a single day passes by without a call for expanding our use of renewable energy and resources. This comes as a result of already serious shortages of many non-renewable resources, and the rapid increase in human population world-wide which leads to soaring demand for more and more resources. Some of the non-renewable resources which are essential for the scientific and technological advancements and the sustainability of the modern life style are Earth's ore minerals. An ore is "a mineral or mineral aggregate containing precious or useful metals and that occurs in such quantity, grade and chemical combination as to make extraction commercially profitable" (Christensen, 1999, p. 644).In considering ore minerals and the valuable elements they contain, two interesting and important facts come to light. First, mineral deposits are not evenly distributed around the world or even

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around a given region or country. Second, as a result of changes in the value of many elements, and in the technologies available to recover those elements, "some mineral deposits that are classified as ores today weren't ores a few years ago and vice versa" (Christensen, 1995, p. 131). One little known group of commercially valuable ores isthose that contain the rare earth elements or lanthanides. Some of these elements have become so strategically important that a number of countries have started to preserve their own deposits of these ores in the interest of national security. Simply because the world demand will soon exceed the increasing supply of these types of elements based on the facts that in 2015 for example, the world's industries are forcast to consume an estimate of 185,000 tons of such rare earth elements (Folger 2011). Today, for example, China alone controls approximately 97 percent of the world's rare earth element market (Alonso, et al, 2012; Hurst, 2010). A discussion of the rare earth elements and the minerals and rocks in which they typically occur provide the introductory STEM students, especially in geoscience, earth, and environmental science student with a perspective on economic minerals that are found in minute quantities in some rocks that must be processed in complex physical and chemical methods.

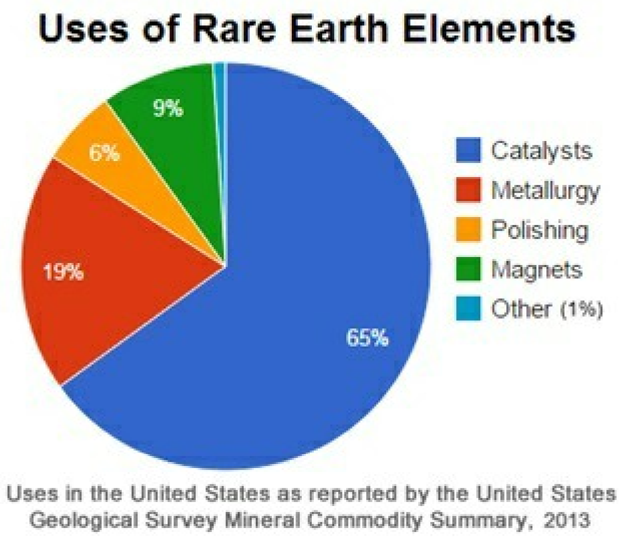
In the role-playing learning activity that follows, students research the rare earth elements (lanthanides) and the short-term and long-term effects of mining these elements in the USA on the economy, scientific and technological advances, the environment and overall well-being of society. Students work together to develop a convincing argument to support or oppose a government plan to promote the mining of lanthanides (rare earth elements) in the USA. By actively engaging in this activity, students learn and reinforce their understanding of the lanthanides and other strategically important resources, their properties and characteristics, commercial extraction and uses, etc. They also learn to take on the roles of others, thus improving their social skills and academic performance. We aim to invoke an interest in learning about the roles of lanthanides in modern scientific discoveries and technological advances, and to excite students to start thinking about the potential for shortages of lanthanides and other strategic resources in the future. This is an issue that will likely be theirs to solve as the next generation of scientists, researchers, industry and business leaders, politicians and policy makers and informed citizens.

Background:

The Rare Earth Elements (Lanthanides):

Most of our students have probably never heard of the rare earth elements (REE) (lanthanides), nor are they aware, for example, that the eyeglasses they wear or the computers, cell phones and ipods they use all have critical components that incorporate the rare earth elements (Aldersey-Williams 2011; Fletcher 2011). Indeed, as Tim Folger recently wrote, "From smart phones to hybrid vehicles to cordless power drills, devices we all desire are made with a pinch of rare earths-exotic elements that right now come mostly from China (2011, ¶ 1). This type of lack of awareness is somewhat surprising in light of the fact that these elements are key materials in the glass, electronic, and metallurgical industries, as well as many other advanced and high-technology products. The rare earths include 15 naturally-occurring elements on the periodic table with atomic numbers 57-71 (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium). Scandium (atomic number 21), and yttrium (atomic number 39) are grouped with **lanthanides** family because of their similar properties (Hurst, 2010; Huang and Bian, 2010). All t**he rare earth elements (Lanthanides)** are metals, non-soluble in water, and are called "rare earths" because when they were discovered, "they were not widespread and were difficult to identify and separate from their ores by their discoverers" (Clark, 2004, p. 426). Although collectively somewhat sparse in large amounts, they tend to all be found mixed together in the same locations on Earth, are (still) surprisingly difficult to purify, and are commercially important because of their ability to resist heat, chemical attack by water, oxidation, etc.

Uses of Rare Earth Elements - Methals:



Source: http://geology.com/articles/rare-earth-elements/

Table 1: The Lanthanide Elements and Some of Their Characteristics (Huang, 2010)

Lanthanide Elements and Some of Their Characteristics				Electronic configurations of neutral atoms					Light or Heavy of Rare Element**
Element		Atomic Number	Atomic weight						
Name	Symbol			4f	5s	5p	5d	6s	
Lanthanum	La	57	138.91	0	2	6	1	2	Light
Cerium	Ce	58	140.12	1	2	6	1	2	Light
Praseodymium	Pr	59	140.91	3	2	6		2	Light
Neodymium	Nd	60	144.24	4	2	6		2	Light
Promethium	Pm	61	(147)	5	2	6		2	
Samarium	Sm	62	150.36	6	2	6		2	Light
Europium	Eu	63	151.96	7	2	6		2	
Gadolinium	Gd	64	157.25	7	2	6	1	2	Heavy
Terbium	Tb	65	158.93	9	2	6		2	Heavy
Dysprosium	Dy	66	162.5	10	2	6		2	Heavy
Holmium	Ho	67	164.93	11	2	6		2	Heavy
Erbium	Er	68	167.26	12	2	6		2	Heavy
Thulium	Tm	69	168.93	13	2	6		2	Heavy
Ytterbium	Yb	70	173.04	14	2	6		2	Heavy
Lutetium	Lu	71	174.97	14	2	6	1	2	Heavy
				3d	4s	4p	4d	5s	
Scandium*	Sc	21	44.96	1	2				
Yttrium*	Y	39	88.91	10	2	6	1	2	Heavy

*. As shown in the table, for lanthanide elements, "as the atomic number increases an electron is not add to the outermost shell but rather to the inner 4f shell" (Huang and Bian, 2010, p. 2). Scandium (atomic number 21), and yttrium (atomic number 39) are grouped with lanthanides family because of their similar properties (Hurst, 2010).
**The light rare earth elements (atomic number 57-62) are more abundant than the heavy ones (atomic number 64-71 plus yttrium). The heavy rare elements which are not abundant as the light ones are generally used in high tech applications (Hurst 2010).

As shown in table 1, all the rare earth elements share a specific location within the periodic table and have very similar chemical properties. They are located in the sixth period of the periodic table starting with atomic number 57 (lanthanum) running sequentially to 71 (lutetium). Scandium (atomic number 21), and yttrium (atomic number 39) are grouped with lanthanides family because of their similar properties (Hurst, 2010). They all share the same number of electrons in the O and P shells, while each successive element adds electrons to the N shell. Since the chemical properties of elements are largely due to the number of electrons in their outer shell, all the rare earth elements have very similar chemical properties (Emiliani, 1995, p. 18). These elements are also collectively called inner transition metals, and are quite unlike any of the other transition metals.

> *"The sixth-period inner transition metals are called the lanthanides because they follow lanthanum, La. Because of their similar physical and chemical properties, they tend to occur mixed together in the same locations in the earth. Also because of their similarities, lanthanides are unusually difficult to purify. Recently, the commercial use of lanthanides has increased. Several lanthanide elements, for example, are used in the fabrication of the light-emitting diodes (LEDs) of laptop computer monitors." (Hewitt, Lyons, Suchocki, and Yeh 2007, p. 232-3)*

Historically speaking,

> *"Compounds of the rare earths were first identified when they were isolated from uncommon minerals in the late 1700s. The elements are very reactive and have similar chemical properties, so they were not recognized as elements until some fifty years later. Thus, they were first recognized as earths, that is, non-metal substances, when in fact they are metallic elements. They were also considered to be rare since, at that time, they were known to occur only in uncommon minerals. Today, these metallic elements are known to be more abundant in the Earth than gold, silver, mercury, or tungsten. The rarest of the rare earths, thulium, is twice as abundant as silver. The rare earth elements are neither rare nor earths, and they are important materials in glass, electronic, and metallurgical industries." (Tillery, Eldon, & Ross, 2008, p. 190)*

In addition, there is a second group of inner transition elements, located in the seventh period of the periodic table, directly underneath those in the sixth period. The second series of inner transition elements is called the actinide series, because they follow actinium (89), and they include the three naturally occurring elements thorium (90), protactinium (91) and uranium (92), and then a series of artificially produced elements not found in nature (table 1 and 2).

Together, the two series are called the inner transition elements. The top series is fourteen elements wide from elements 58 through 71. Since this series belongs next to element 57, lanthanum, it is sometimes called the lanthanide series. This series is also known as the rare earths. The second series of fourteen elements is called the actinide series. These are mostly the artificially prepared elements that do not occur naturally." (Tillery, Eldon, & Ross, 2008, p. 190)

Why Rare Earth Elements Are So Important:

Because they are insoluble in water and resistant to the action of heat, rare earth elements are key materials in many advanced or high-technology products:

Lanthanum, for example, gives glass special refractive properties and is used in optic fibers and expensive camera lenses. Samarium, neodymium, and dysprosium are useful to manufacture crystals used in lasers. Samarium, ytterbium, and terbium have special magnetic properties that have made possible new electric motor designs, magnetic-optical devices in computers, and the creation of a ceramic superconductor. Other rare earth metals are also being researched for use in possible high-temperature superconductivity materials. Many rare earths are also used in metal alloys; for example, an alloy of cerium is used to make heat-resistant jet engine parts. Erbium is also used in high performance metal alloys. Dysprosium and holmium have neutron-absorbing properties and are used in control rods to control nuclear fission. Europium should be mentioned because of its role in making the red color of color television screens. The rare earths are relatively abundant metallic elements that play a key role in many common and high-technology applications. They may also play a key role in superconductivity research." (Tillery, Eldon, & Ross, 2008, p. 190)

Finally, as Hurst (2011) has argued:

The term rare earth is actually a misnomer; these elements are not rare at all, being found in low concentrations throughout the Earth's crust and in higher concentrations in certain minerals. REEs can be found in almost all massive rock formations. However, their concentrations range from ten to a few hundred parts per million by weight. Therefore, finding them where they can be economically mined and processed presents a challenge. (p. 122)

Furthermore, because of the difficulty in acquiring the rare earth elements, and the lengthily processes in extract and producing them from a given ore containing minerals, scientists in fields such as plant science, soil science, and environmental science have started to study the effect of rare earth elements on soil, agriculture, and the environments especially in East Asian agriculture (Tyler, 2004; Alonso, 2012).

Table 2: Lanthanide Series

	Name of Element	Symbol, Atomic Number, Year of Discovery and by Whom				Commercial Uses
		Symbol	Atomic #	Year	By	
1	Lanthanum	La	57	1839	Carl Gustaf Mosander	
2	Cerium	Ce	58	1803	Jons Jakob Berzelius, Wilhelm Hisinger	
3	Praseodymium	Pr	59	1885	Car Auer, Freiherr von Welsbach	
4	Neodymium	Nd	60	1885	Car Auer, Freiherr von Welsbach	
5	Promethium	Pm	61	1945	Charles DuBois Coryell & his team	
6	Samarium	Sm	62	1879	Lecoq de Boisbaudran	
7	Europium	Eu	63	1901	Eugene-Antole Demarçay	
8	Gadolinium	Gd	64	1888	Jean-Charles-Gallisard de Marignac	
9	Terbium	Tb	65	1843	Carl Gustav Mosander	
10	Dysprosium	Dy	66	1886	Lecoq de Boisbaudran	
11	Holmium	Ho	67	1878	Marc Delafontaine, Jacques Louis Soret, Per Teodor Cleve	
12	Erbium	Er	68	1838	Carl Gustav Mosander	
13	Thulium	Tm	69	1879	Per Teodor Cleve	
14	Ytterbium	Yb	70	1817	Jean-Charles-Gallisard de Marignac	
15	Lutetium	Lu	71	1907	Georges Urbain	

Warm-Up activity (optional, based on the level and needs of individual classes):

1. Ask each student to distinguish between element, compound, homogeneous mixture, heterogeneous mixture, and ore and provide an example of each. Students may use Table 3 to respond.
2. All the materials you encounter on and in the planet Earth are made up of various combinations of about 90 elements. However, only 10 elements make up over 98% of the Earth's crust (by weight). Have students name these 10 elements and give their percentages in Earth's crust, using Table 4 for their responses.
3. Prior to students doing any outside research, ask each student to use Table 5 to name, give reasons for their choices, and list uses for:
   a. the three most expensive elements in the world,
   b. the three rarest elements in the world,
   c. the three most important elements in the world. When they finish, collect the assignment from them and keep for the following class meeting.
4. Ask each student to conduct research to learn about the most expensive elements, the rarest elements and the most important elements, and to write a 1-2 page paper about what they have learned.
5. In the following class meeting return to the students their table 5 which you collected earlier and provide each one of them with a new unfilled copy of the same table. Ask the students to fill out the new Table 5 based on what they have learned and to compare their two versions of the table.
6. Ask the students to reflect on what they have learned from engaging in this activity.

Table 3: Element, compound, homogeneous mixture, heterogeneous mixture, and Ores

	Distinguish between and provide example of			
	Name	Definition	Characteristics	Example
1	Compound			
2	Element			
3	Heterogeneous mixture			
4	Homogeneous mixture			
5	Ores			

Table 4: The percentage by weight of the 10 most common elements in Earth's crust

	Element (in order of abundance)	Symbol	Atomic Number	Atomic Mass	Percentage by weight In Earth's Crust	Additional Notes
1	Oxygen	O	8	16	45.2%	
2	Silicon	Si	14	28.09	27.2%	
3	Aluminum	Al	13	26.98	8%	
4	Iron	Fe	26	55.85	5.8%	
5	Calcium	Ca	20	40.08	5.06	
6	Magnesium	Mg	12	24.31	2.8%	
7	Sodium	Na	11	22.99	2.3%	
8	Potassium	K	19	39.1	1.7%	
9	Titanium	Ti	22	47.87	0.9%	
10	Hydrogen	H	1	1.008	0.1%	
11	Manganese	Mn	25	54.94	0.1%	
12	Phosphorus	P	15	30.97	0.1%	

Table 5: The most expensive, important, and rare known elements

Type of Element	Selected Elements			
		First	Second	Third
The Expensive Elements	Name of the Element			
	Reason Why			
	Commercial Use			
The Rarest Elements	Name of the Element			
	Reason Why			
	Commercial Use			
The Most Important Elements	Name of the Element			
	Reason Why			
	Commercial Use			

Whether they are really rare or normally abundant, the lanthanides are very important elements in development of scientific and technological advancements as well as in the manufacture of a wide range of household electronic devices and scientific equipment.

Learning Activity:

Rare Earth Elements (Lanthanides) and Their Significant Roles in Society:

In this learning activity, students work in groups of 3-4 to research the rare earth elements that are called lanthanides, their availability, extraction, benefits and commercial uses world-wide. Students should look at both the short-term and long-term effects of mining for these elements in the US, in terms of both benefits and challenges, to the economy, the environment, scientific and technological advances, and the overall well-being of society as a whole. Then, each group selects one of the following interest groups to research and represent:1) industry and business community, 2)geologists, 3) environmentalists, 4)politicians and policy makers, 5)economists, 6) public interest advocates, and 7) local public media. Each group of students is required to design convincing arguments, based upon the likely opinions of their chosen interest group, that either strongly support or strongly oppose the government encouraging the mining of lanthanides (rare earth elements) in the United States by giving financial incentives to mining companies and easing the regulations and environmental restrictions governing the mining of these elements. Once the members of the groups have finished their research, they prepare a written report and an oral presentation to be given in class. To accomplish this goal, students work together to research lanthanides and collect information about their selected interest group.

Procedure:

Before Presentations:

1. Form a debate committee that consists of the instructor of the class, another instructor in the school, and one academically respected student from the same class (or have a "class vote/peer review" at the end of the presentations).
2. Divide the class into groups of 3-4 students, and direct each group to work together to:

   a. Conduct research about lanthanides and their roles in the modern scientific discoveries and technological advances. See table 1 and 2.
   b. Select one interest group (coordinated by the instructor to avoid duplication) and then prepare a written paper, hand-out, and oral presentation on the point of view of the chosen interest group. The presentation must convey information and integrate the use of effective presentation strategies such as PowerPoint, animations, interactive activities, etc.
3. Ask each group to prepare two critical thinking questions to submit for inclusion in a pool of questions for class quizzes or examinations.
4. Give the students 2 to 3 weeks (time can be shortened or lengthened) to prepare their written paper, hand-out, and presentation.
5. At every class meeting, make sure that students are working on their assignments. For example, give 10–15 minutes to the members of each group at the end of the class meeting to sit together and reflect on the progress they have made toward the written paper, poster, additional aids, and the oral presentation.
6. Students are advised to start their research by reading at least 3 of the following articles which can easily be found in the school library or any nearby public library:

   a. Aldersey-Williams (2011).
   b. Fletcher (2011).
   c. Folger (2011).
   d. Hurst (2010; 2011)
   e. Tahil 2006
   f. REE - Rare Earth Elements and their Uses (2011) http://geology.com/articles/rare-earth-elements/
7. Remind the students that the objectives in this learning activity are to help them develop:

   a. Breadth of knowledge and depth of understanding of concepts and vocabulary of the lanthanides, their properties and characteristics, commercial uses, and their importance in future scientific and technological developments.
   b. An understanding of the social, economic and environmental implications and limitations of science, technology, and engineering.
   c. An awareness of their own attitudes, feelings and values about environment, the rights of future generations, and how their personal opinions differ from those of others.
   d. An awareness of the importance of lanthanides in environmental protection/stewardship, economy and sustainability.
   e. Team work and communication skills.
   f. Critical thinking and problem-solving skills.
8. You may wish to assign each group a particular interest group to focus on and represent. If you do so, then you need to provide additional specific questions that each group members must address.

During the Presentation:

1. The groups take turns presenting their perspectives to the debate committee and the rest of the class by providing convincing argument to support their views on encouraging the mining of the lanthanides (rare elements) in the USA by giving financial incentives to the mining companies and easing the rules and policies governing such mining operations.
2. The debate committee questions each group. In addition, the students in the class can ask up to three questions after a group finishes its presentation. The members of each group take note of all the questions that are asked.
3. When all the groups have presented, the members of the debate committee can ask more questions to all the groups. The students from any group can also ask questions directed to any other group, which the

members of the debate committee may consider in their final judgment and decision. The members of each group must also take notice of all the questions that were asked.

4. The members of the debate committee wait until the next class meeting before sharing their final decision with the groups. During this time, if there is room in the school, the posters, illustrations, and other presentation details can be made available for all the students to view.

After the Presentation:

1. In making their final decision, the members of the debate committee take into consideration the following (a–c):

    a. The academic quality and integrity of the written paper, the oral presentation, the poster illustration, and/or any additional aids used by the students to convey their message.
    b. The delivery of the presentation, the articulation of the perspective and arguments, the demonstration of the long term and short term effects, and each individual's personal involvement and engagement during the debate.
    c. The type and quality of questions asked during the debate. In addition, the quality of the answers the group provided to questions directed at them. Teachers and instructors can refer to Cherif et al. (2009) for useful tools and techniques that can be used to monitor the level of cognitive involvement of the members of a given group during the activity as well as to record the types of questions being asked by the members of a group, the relevance of the questions to the subject matter and to the point being debated, and the number of questions asked by the members of each group, as seen in Appendix 1.
2. Before the chair of debate committee reads and defends the committee's final decision, each group is given 2-3 minutes to address the committee one more time. In this short final remark, the groups must have a written statement that can be read to support their case.
3. After all the groups present their final remarks; a representative of the debate committee reads and defends the committee's final decision.
4. The instructor of the class must reinforce the principle of matter and energy, renewal and non-renewal resources, requirements for a substance to qualify as mineral, differences between atoms, molecules, ins, etc., the fact that today, no country including the USA is able to supply all its mineral demanded and needs, mining and land surface and underground water, mining related problems and their scientifically creative solutions.

Assessment:

The post-activity discussion is very important for students' cognitive and social development because it encourages understanding of the social and personal dynamics involved in reaching a conclusion. The teacher and students should explore how and why each group reached its decision, and whether this situation could have been approached in other ways (Joyce, Weil, and Calhoun, 2009). In assessing students' performance and understanding, as well as the effectiveness of these activities, we have been using McCormack and Yager's (1989) taxonomy for science education as a framework for student achievement (e.g., Cherif, Verma & Somervill, 1998; Cherif & Somervill, 1994, 1995).A summary of this taxonomy can be found in Cherif et al. (2009). In the same article, teachers and instructors can also find useful tools and techniques for monitoring the level of cognitive involvement of the members of a group during the activity and recording the types of questions being asked by the members of a group, the relevance of the questions to the subject matter and to the point being discussed and debated, and the number of questions being asked by the members of each group (see Appendix 1).

Furthermore, using both formative and summative assessment, students' performances are evaluated based on:

1. How well they:

    a. Conduct their research.
    b. Presented their research and made it personal and relevant.
    c. Show the significance of their arguments during the presentation.
    d. Respond to the questions asked by their classmates after their presentations.
2. How many critical thinking questions they submit for inclusion in the quizzes and examination pool.
3. How well they completed the homework assignment and answered the related questions.
4. The academic quality and integrity of the written paper, the hand-out, the oral presentation, and/or any additional aids used by the students to convey their message.
5. Clear evidence that the members of a given group conducted research beyond the suggested articles assigned by the instructor for all the students to read.
6. The delivery of the presentation, the articulation of the perspective and arguments, the demonstration of the long term and short term effects, and the individual's personal involvement and engagement during the presentation.
7. The type and quality of questions asked and the quality of the answers the group provided to questions directed at them. Teachers and instructors can refer to Cherif et al (2009, 2010, 2011) for useful tools and techniques that can be used to monitor the level of cognitive involvement of the members of a given group during the activity as well as to record the types of questions being asked by the members of a group, the relevance of the questions to the subject matter and to the point being debated, and the number of questions asked by the members of each group.

The instructor of the class should use the assessment phase discussions to reinforce basic scientific principles like oxidation or superconductivity (based on the exact nature of the class in which the activity is used), or to reemphasize issues like the role of rare earth elements in the development of science and technology, biological diversity, environmental sustainability, economic prosperity, and public health.

Student Level of Involvement in the Learning Activity

To make the teaching approach of the given learning activity more productive, teachers should lead students toward greater levels of involvement in the process by including them in planning the five factors that make up a typical role-playing situation: the problem to be solved, the characters to be played, the roles to be followed, essential information to be gathered, procedures for the play to be adapted (Cherif & Somervill, 1994, 1995). The educational value of the role-playing activities increase as the procedure encompasses greater levels of student involvement. In this activity, the problem to be solved and the characters to be played are given to the students. However, the roles to be followed, the essential information to be gathered, and the procedures for the play to be adapted are part of the learning activity and the students' responsibilities. Thus it is at the fourth level of involvement in the learning activity. As the difficulty level increases, so does the amount of time, effort, and best of all, enthusiasm among the students. The final level of involvement is critical assessment.

Instructors can use Tables 6, 7, and 8 as tools to record information and to monitor the level of cognitive involvement of the members of a given group during the activity. In Table 6, instructors can record the type of questions being asked by the members of a given group as well as the relevancy of the questions to the subject matter and to the point being debated. In Table 7, instructors can record the number of questions being asked by the members of a given group to the other groups.

Pre- & Post-Test Homework Assignments

To reinforce the learning objectives of the activity and to allow for compiling attitudinal change data, ask the students to answer the following questions, either individually or in groups.

Pre-Test Homework Assignment

1. What do you expect the final decision made by the members of the debate committee to be? Do you think you would agree with it? Why or why not?
2. What do you think you will learn from the activity at both the academic and personal levels?
3. What will you do to make sure that the final decision reached by the members of the debate committee is in your favor?

Post-Test Homework Assignment

1. Reflect on the final decision made by the members of the debate committee. Do you agree with it? Why or why not?
2. What have you learned from the activity at both the academic and personal levels?
3. If you had to do this all over again, what would you change or do differently and why?

Discussion Questions:

1. What are the most significant characteristics of rare earth elements (lanthanides).
2. Why were the lanthanides for a long time called “rare earth elements?” How did their present designation as “lanthanides” originate?
3. Where, on or in Earth, have most of the lanthanides been found?
4. Which country or countries mine and extract most of the lanthanides in the world?
5. Which country or countries import and use most of the lanthanides in the world?
6. Why have most of the mining sites of lanthanides in the United States closed or significantly reduced their productive capacity?
7. Under what circumstances might the United States exceed China in the production and export of lanthanides?
8. From your perspective, how might we be able to produce more lanthanides without harming the environment and compromising with the future of the next generation?
9. Can any other more abundant elements be made to have the same useful characteristics as the lanthanides?
10. It has been said that those countries which have an abundance of lanthanides are going to lead the scientific discoveries, technological advancement and be among the most influential countries of the world. Do you agree or disagree and why?
11. Why do you think scientists are not discovering these days any more of the elements with the lanthanide’s special characteristics?
12. In the United States, gold deposits are concentrated in California, Nevada, Colorado, Alaska, and North Carolina, but not in Nebraska, Minnesota, or Alabama. What does this tell you about the mineral deposit distribution within a given country?

Homework Assignment:

When all the groups complete their presentations, give the homework assignments in appendix 1 to students to work on and complete individually or in groups.

Conclusion:

Today, human societies are faced with many complex challenges including, environmental, economic, technological, rapid increase in human population, and scarcity of non-renewable resources, to name a few. These types of challenges require revolutionary approaches to understanding that today's countries and human societies of our world as integrated and interdependent in global environment with limited non-resources.

Because of this, understanding the status of the world's non-renewable resources including the rare elements is necessary to enhance our understanding of ourselves and how we can solve many of the challenges that are facing us today, such as: global environmental changes, the use of biologically-based energy resources, restoring healthy ecosystems, and maintain the superiority of our society as a leading scientific and technological society in the world.

In this learning activity, we have tried to create a strategy of role playing that enables students to become more actively involved in learning about non-renewable resources and their role in the development of scientific and technological advances. Choosing a stance, either *to support or oppose the government allowing the mining of the lanthanides (rare earth elements) in the USA by giving financial incentives to the mining companies and easing the rules and policies of mining these elements*, and debating that opinion among classmates improves student's communication, collaboration, and critical-thinking skills, and it enables them to have fun and enjoy learning.

The activity can be conducted before or after this topic is covered in class. In both cases, the wrap-up or ending discussion is important because it drives home the importance of *mining these elements in the USA and its effect on the economy, scientific and technological advances, the surrounding environment and prosperity of the society*. In our case, this role-playing activity has benefited some of our students, from middle school to high school to college levels, by motivating them to engage in deep learning that results in a meaningful understanding of material and content.

Answers to Questions Raised in the Learning Activities:

A complete and detailed list of answers to all the questions raised in the learning activities in this paper are available electronically based on individual request by e-mailing any of the authors.

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Appendix 1

Tables 6, 7, and 8 Those need to be inserted after the Assessment Section.

Table 6: Individual group questions analysis and account.
(Cited from Cherif, *et.al*, 2009, p. 350)

	Type of Question or Conditional Statements	Extremely Relevant	Relevant	Less Relevant	Not Relevant	Total of Questions
1	Why					
2	How					
3	What do you think if...?					
4	Which					
5	What					
6	When					
7	Where					
8	Is/Are					
	Total of questions and or wondering statements					

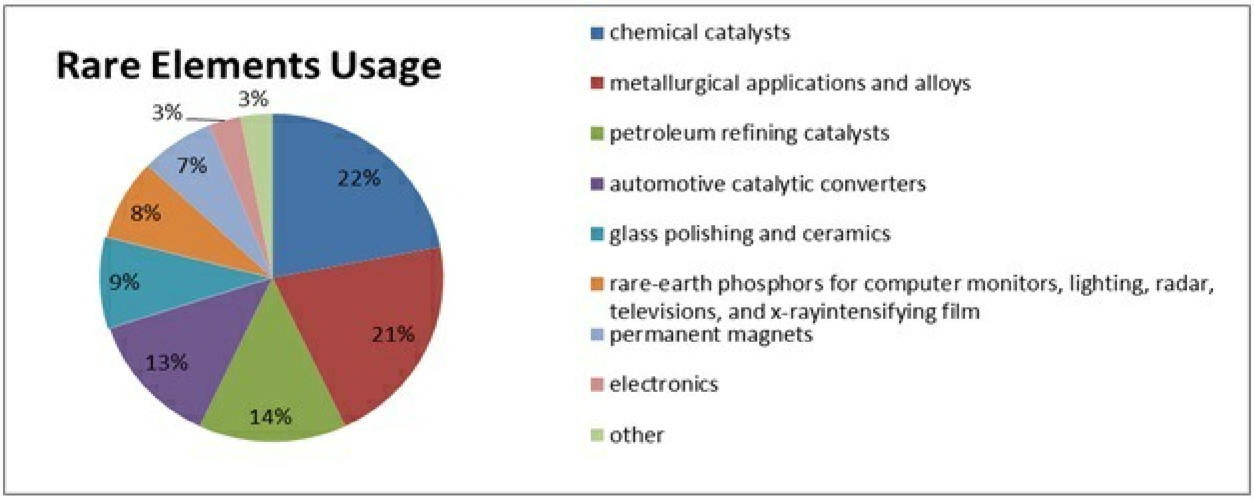
Table 7: Tracking the number of question asked by each group of other groups
(Cited from Cherif, *et.al,* 2009, p.351)

	Industry & business community	*Geologists*	*Environmentalists*	*Politicians and policy makers*	*Economists*	*Public advocates*	*Media*
Industry & business community	X						
Geologists		X					
Environmentalists			X				
Politicians and policy makers				X			
Economists					X		
Public advocates						X	
Media							X
Total of Questions							

Table 8: Type of Questions or conditional statements and their values for assessment purposes (Cited from Cherif, et.al, 2011, p.20)

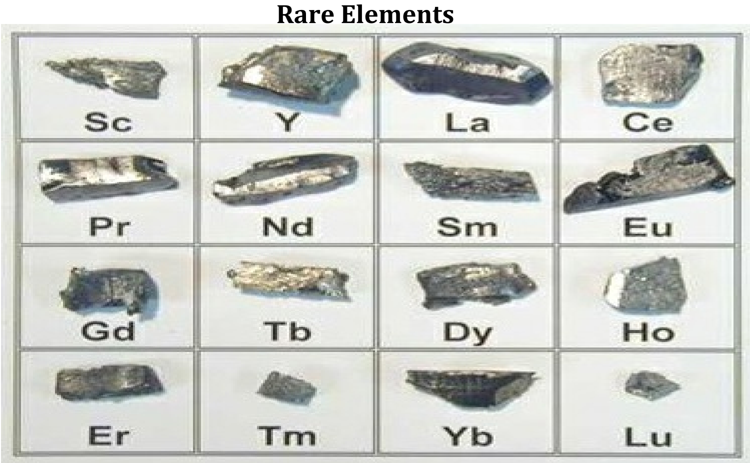
	Type of Question	Extremely Relevant			Relevant			Less Relevant			Not Relevant			Total
		# of Quest-ions	Value Per-Quest-ions	Total Values	# of Quest-ions	Value Per-Quest-ions	Total Values	# of Quest-ions	Value Per-Quest-ions	Total Values	# of Quest-ions	Value Per-Quest-ions	Total Values	
1	**Why How**		5			4			3			1		
2	**What do you think if...**		4			3			2			1		
3	**Which**		3			2			1			0.5		
4	**What When Where**		2			1			0.5			0		
5	**Is Are**		1			0.5			0			0		
	Total													

Rare Elements Usages



Source: Data obtained from the US ecological survey of the US Department of Interior. Mineral Commodities 2011[13]. https://borjafernandezburgueno.wordpress.com/tag/rare-earth-elements/

Rare Elements



Source: http://www.cleanbreak.ca/2011/01/

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