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MODERN COSMOLOGY, A RESOURCE FOR ELEMENTARY SCHOOL EDUCATION

GEORGE V. COYNE

Introduction

The wisdom which has already come to light in this symposium has reinforced for me the following ideas which I would like to collect, if possible, into a single argument which I will try to establish by providing an example of teaching an actual class to elementary school students. You assembled Academicians and invited scholars are to be my class.

The ideas which I have garnered are the following: (1) we should start teaching children from where they are at present, their current knowledge, interests, fears, and so on; (2) all of us humans, those who teach and those who are taught, "have been made in heaven", it has been said. This refers to the well known need for stellar nucleosynthesis to provide the chemical abundances required for life in the universe. It has been indicated that one of principal goals of teaching children should be an awareness of this birth of ours from star dust, if only at an elementary level. I would suggest that the didactic order be reversed and that this awareness should be the beginning point of elementary school education; (3) the aim to develop "scientific literacy" has been a recurrent theme but I have not heard it defined. I propose an elementary definition which suits the purposes of my presentation: To be scientifically literate means to have an understanding of ourselves in the *physical* universe (the emphasis being on *physical,* but with the implication that I am speaking of all of the natural sciences: biology, physics chemistry and their derivatives); (4) Much has been made of the distinction between the methodology and the content of teaching. I would like to suggest that these two aspects of elementary school teaching find a unity in an ideology, a guiding theme, a single dominant perspective on ourselves in the physical universe.

"Being" versus "Doing"

My aim in this presentation is to show by a living example that the unifying theme of our birth from star dust can serve as an effective and entertaining way of introducing children to the elements of science. So let me begin, but first I must share with you an important but hidden conviction of mine which may not become apparent to you as I teach. For many years I have taught a general astronomy course to college freshman. In an evaluation of the course after about one month I received a recurrent refrain: "This course is fascinating and full of very interesting and new ideas, but it is useless". After many attempts at trying to refute that remark, I finally realized that it is correct. The course is "useless", if that expression is understood correctly. Philosophers distinguish, I am led to understand, between "being" and "doing". A knowledge of astronomy helps us to "be", not to "do". It shares, in that regard, with the visual arts, with music, with sports. Astronomy will not help me repair my car or make better toothpaste, but it will help me be a more interesting person, to myself and to others. It will help me to participate in a richer way in our adventure as beings in the physical universe. Many of the other sciences, of course, share in this "useless" nature of knowledge, but astronomy, I hesitatingly assert, does so in a preeminent way. So that is why I have chosen to teach it to children. I would never, of course, admit to my class of elementary school students that this year's course is useless. Children are already convinced of that without realizing it. They are quite content to grow in "being" and surrender the doing to "adults". Let us begin. Remember I am teaching you a year-long course in fifteen minutes. This is an introductory class to elementary school students in which many themes are only introduced and will be elaborated on during the year. These children are somewhere between the ages of 8 and 14. I am afraid my inadequate understanding of this age group will cause me to wander a bit in the range of difficulty of the ideas to be comprehended. I repeat, you are my class, at least for the next fifteen minutes.

A Class Taught to Children

Welcome, children. This year we are going to study about the world in which we live, mostly about the world way out there. But we will also be studying about ourselves, because, as you will see, we are part of the world and, although they are a long way out there, the stars are in some ways very close to us. It is going to be fun to see how close we are to the stars, even more fun than taking a picnic to the seaside or to the mountains. At least, I am going to have fun and I think you will too. And as we have fun, we will also see how important science is because science is one of the ways in which we can bring all of those objects way out in the universe close to ourselves.

You know how much fun it is at night to look up at the stars and try to see how, when we tie them together with lines between them, we can imagine various faces and animals and soldiers and our heroes. Take Orion, for example. Our ancestors, thousands of years ago linked up those stars and saw one of their great heroes, the hunter Orion, up there in the sky. And in front of him they saw the bear he was hunting and behind him his little hunting dog. These are what we call constellations and we will study about them this year.

But let's begin to think like astronomers think. Are all of those stars at the same distance from us? The answer is NO, but it took many years to find that out and it will take us this year some time to understand that NO. But let us begin by doing a simple experiment. Hold a pencil up a little bit in front of your nose, close your left eye and with your right eye look at my head. Now close your right eye and look with your left eye. Now blink your eyes like that many times. What is happening? Yep, the pencil is sliding to the right and to the left of my head. Now hold the pencil at arms length. What happens? Yep, the shift of the pencil with respect to my head still occurs but it is smaller. Now let us go out to the playground. Hold up the pencil again but now look at that tree down the street and then look at the top of that mountain out there? What is happening? Yep, we have noticed two things. When I look at a distant object the closer I hold the pencil to my nose the larger the shift and, if I keep the pencil at the same distance from my nose, then the shift is less for more distant objects. We have just discovered what astronomers call "parallax" and we will study this year how we can use it to measure the distances of the sun, the moon, the stars and even galaxies. We will soon talk about all of those objects.

Now we are becoming scientists so we have to ask more questions. Why is there the shift we have observed and why is the shift different for different distances of the pencil and the distant objects I am looking at: my head, the tree, the mountains. What would happen if your two eyes were together in the middle of your head, like those big giants in fairy tales? You guessed it! There would be no shift. It is because our eyes are separated that we see the shift. But the stars are so far away that the small distance between our eyes will not allow us to see them shift. What if we could separate our eyes by very large distances? Well, astronomers have found a way to do that. Can anyone guess how? We will find out later in the year.

When we study "parallax" later on in more detail, we will really become astronomers and will know that the stars we see in Orion are at various distances from us, some of them thousands of times further away than others. They only appear to be at the same distance because our eyes are too close together. In fact, we see everything beyond the Earth, even spaceships, as if they were at the same distance, on what astronomers call the "plane of the sky". Now that we have discovered this, let us look back at the stars in Orion.

With big telescopes – and we still study about telescopes later on – let us look at the belly of Orion. What we see is boiling gas and dust and, if we look very carefully, we see that some of the gas is red and some is blue and that the red and the blue are separated. Remember as scientists, when we see something like that, we have to find out why. Actually the red gas is the result of energy being transferred from stars to the gas, where that energy is swallowed up and then sent on to us. We will study about this later on. The blue gas is the result of starlight being reflected towards us, not swallowed up, just like light is reflected from a mirror; but the mirror in this case is the cloud made up of millions of gas and dust particles. Do you know why the sky is blue? It is for the same reason: sunlight is reflected from the particles in the Earth's atmosphere. But let us return to the discussion of the red gas.

Deep inside that gas new stars have been born. Yes, that is one of the marvels of the universe. Stars are born. They have a very long lifetime and it takes them a long time to be born. But we will learn later on that a star like the sun – yes, the sun is a star like all of those we see in the sky – was born more than twice as fast as we are, if we consider how long it lives. (I would introduce here the concept of the relative measures of time and distance, to be discussed in more detail later on. The sun was born in about 2×10^7 years and will have a total lifetime of about 10^{10} years; we are born in about 1/100th of our lifetime). The stars are very far away, so we do not see them being born, but we will see how astronomers can know about their birth. In fact, the red light that we receive gives us a clue to the birth of stars.

But what is light and what do we mean by swallowing up energy? Light is energy and, in this case, it comes from the stars. We will study about different kinds of energy. Light is one kind. It is called radiant energy and it travel in waves. Let us now do an experiment to show how light travels in waves. (See Appendix I for an experiment which I would now do with the children to introduce the wave nature of electromagnetic radiation. I would do this experiment in this introductory lecture so that the children could have fun and realize that the course will have many other experiments and not consist only in lectures). In order to understand what we mean by energy from the stars being swallowed up by the gas, let us do another experiment. (See Appendix II for a second experiment that I would do with the children on the absorption and reradiation of electromagnetic energy).

Stars are born in the following way. A big cloud of gas and dust in the universe begins to break up and the pieces begin to collapse. As a gas collapses it heats up and as it expands it cools down. We will study about why this occurs later on this year. The piece of the cloud that collapses weighs many times more than the sun and so it heats up to millions of degrees in its center so that it creates a kind of atomic bomb by turning hydrogen into the heavier elements. (Here I would introduce the difference between weight and mass with the promise to study it in more detail later on). This is a kind of nuclear energy. Later on this year we will study what we mean by nuclear energy and by light and heavy elements, but I can tell you right now that the gas in the star that was hydrogen will eventually become carbon and then finally iron. So a star is born when it turns on a nuclear furnace and it lives by making heavier elements.

Eventually, however, a star dies, just as happens to everything else in the universe, even to you and me. It is not very nice to think about dying, but in the universe, if stars did not die, you and I would not be here. In order to have the chemicals necessary to make our toe nails and ears and everything that lives in the universe, stars had to make up the heavier elements and spew them out to the universe as they die. Why does a star die? Because it finally has no more fuel for the nuclear furnace and it collapses and then explodes to spew out to the universe many of the heavier elements that it has formed during its life time. We are born of those elements; we are made of star dust.

As we study astronomy this year we will come back time and time again to understand what it means to say that we are born from the stars. We will see that the sun is one of a hundred billion stars in our galaxy, that we call the Milky Way and that there are billions of galaxies like the Milky Way. But one star is very special to us and that is the sun, because planets formed around the sun and one of those planets is our Earth. The planets formed because some of the matter from the piece of a cloud that collapsed to form the sun was left over and, after the sun was born, this material had to collapse into a disk. Why do I say “had to?” The laws of physics, which we will study this year, are the same for the stars as they are for us and for any other object in the universe. The material around the star had to obey a certain law of physics. (I would introduce here with examples the conservation of angular momentum). Do you think planets formed about other stars in the universe? Why do you answer “yes” or “no”.

A marvellous thing has happened on our Earth. We can put the universe in our heads and that is what we are going to do during this year of studying astronomy. Some hundreds of years ago people like us discovered physics and mathematics and the other sciences and now we can use those sciences to find out how the universe works. Let me give you an example. When you go home I want you to weigh yourself and measure how tall you are. Tomorrow I want you to tell me what your weight is and what weight means. And then, without measuring your father’s height, I will want you to tell me how much taller than you he is: two times; 1.3 times? Then we are going to talk about weighing a star and a galaxy and also measuring its size, even though we cannot touch a star or a galaxy. That is the marvel of being able to put the universe in our heads. We can measure the mass and size of stars and galaxies by knowing physics and the other sciences. We are going to have fun doing that this year.

Conclusions

Thank you all for being my elementary school class. What I have tried to establish is that, by using the central idea of our origins in an evolving universe, the principles of physics can be taught in an interesting way by introducing them at a time when the curiosity of the student has been aroused by the search for an answer to a real problem concerning his or her place in the universe. Here is a summary list of some of those real problems and the principles of physics to which they direct the attention of the student, as I have discussed them above:

1. Problem: What are constellations? Principles: distances, parallax, geometry, trigonometry.

2. Problem: how to see further in the universe than our eyes can see? Principles: optics, telescopes.

3. Problem: increasing the distance between our eyes. Principles: think like a scientist.

4. Problem: What is the difference between red and blue gas? Between emission and reflection nebulae? Principles: nature of light, reradiation of energy, reflection of energy, black body radiation and absorption.

5. Problem: How long does it take for a star to be born? Principles: numbers are relative, use of mathematics in science, powers of ten for large and small numbers.

6. Problem: How is a star formed? Principles: difference between weight and mass, gas laws.

7. Problem: How does a star shine? Principles: thermonuclear energy, atomic and molecular nature of matter.

8. Problem: Why does a star die? Principles: hydrostatic equilibrium, metal enrichment of the universe.

9. How do planets form? Principles: rotation, conservation of angular momentum.

I surmise that other sciences might also be able to find a central fundamental thesis which would allow a course development such as the one I propose for astronomy and physics. I leave it to the reader to judge as to whether the four ideas listed in the *Introduction* have been successfully incorporated, in a preliminary way, into the class I have taught.

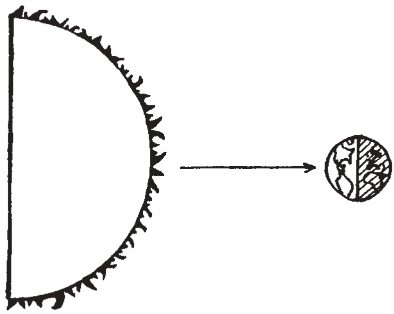
The Vatican Observatory has prepared two booklets of hands-on experiments which would be a key instrument for such a course as the one I envision. They are respectively for grades first to third and fourth to sixth (*Long Eyes on Space: Astronomy and You*, Designed and Developed by the Kino Learning Center [Tucson, Arizona: Vatican Observatory Foundation, 1991]). Samples of two experiments from those booklets are given in the appendices.

Appendices

APPENDIX I. *Long Eyes on Space: Astronomy and You*, II, p. 1.

DOES LIGHT TRAVEL?

People, animals and cars travel through space. Does light travel too?



Light travels from a ***source***, such as the Sun, through space and arrives at Earth in the form of sunlight. Light from ***stars***, other suns in the galaxy, also travels through space and eventually arrives at Earth as starlight. Some starlight comes from so far away that the light arriving at Earth has actually been traveling for millions of miles aver many years.

Light travels in ***waves***, much like those found on the ocean. To discover how light travels, use a simulation, or a model, to see how it works.

Make your own wave simulator to demonstrate how light travels.

Materials needed:

- large tub or pan
- marble
- water
- stop watch
- meter or yard stick

Procedure:

1. Fill the large tub with water, bringing the water level to within one inch of the top of the tub.
2. Drop the marble into the tub from approximately one meter (or one yard) above the water's surface.
3. Observe and record the movement of the water.

Draw and describe your findings

Light waves going through space move much like water waves in the tub. Energy from the Sun is released in the form of radiation, some of which is heat, so sunlight is warm. Starlight does not feel warm because stars afe so far away that the amount of energy that actually reaches Earth is very slight.

APPENDIX II. *Long Eyes on Space: Astronomy and You*, I, p. 11.

LIGHT MEANS ENERGY

Visible light is energy that you can see with the naked eye. The Sun, at the center of our solar system, ***radiates*** or shines this energy in all directions through space. Some of this light energy comes to Earth where it affects everything it touches.

Which is hotter in sunlight, a black object or a white object? To find out, conduct this experiment.

Materials needed:

- 3 large jars of the same size
- 3 thermometers
- black and white construction paper
- sunlight
- water
- clear tape
- aluminum foil
- 3 paper towels

Procedure:

1. Place one crumpled paper towel in the bottom of each jar.
2. Cover the outside of one jar with black paper, one with white paper, and one with aluminum foil. Tape the paper and foil in place.
3. Add equal amounts of water to the jars.
4. Place a thermometer in each jar. Make sure the thermometer rests on the paper towel so it does not touch the jar bottom.
5. Place the jars in direct sunlight.
6. Record the temperature of the water in each jar at the beginning of the experiment and every 15 minutes far an hour.

Record your observations on the chart below.

	Temperature				
Jar type	Beginning	15 minutes	30 minutes	45 minutes	60 minutes
White paper					
Black paper					
Foil					

Which jar had the warmest temperature?______________________________

Which jar had the coolest temperature?______________________________

Why do you think there were differences in temperature?____________________

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If you lived in a desert, what color would you want your house to be in the hot summer?______________________________________

In the cold winter? ______________________________________

