One goal of the Educational Outreach program at MIT's Haystack Observatory is to make a connection between the highly specialized work performed by their scientists and students at all levels. We used one instrument, the MOSAIC system, as the focal point for a multi-level, multi-disciplinary unit.

The public awareness of global climate change has been spurred by an increase in scientific investigations. At the forefront of science, there is a need to slice horizontally across disciplines in a systems approach. We live in a complex atmospheric system, which itself is immersed in a complex Sun-Earth system. Many have heard of the "Butterfly Effect", a theory whereby anything that happens on Earth has influence on everything else – such as the flapping of a butterfly's wing in a tropical rain forest in Brazil causing a hurricane in the Atlantic Ocean a few months later.

At this time, most high school educational standards are vertically integrated into specific subject matter. Budget constraints are threatening to reduce student science options to the core subjects of Biology, Chemistry, and Physics. In eastern Massachusetts, there are only a handful of high schools still offering Earth Science. As students continue to the college and graduate school level, there is a tendency to become more and more specialized into sub-fields of academic research. An old joke goes something like this: *An expert is someone who knows more and more about less and less, until he knows everything about nothing*! This is no longer true of science and scientists – they are learning how connected previously independent subjects and systems can be.

We have developed a simple game, which would work at any educational level and for any complex system. It is fashioned after the anecdotal game "The Six Degrees of Kevin Bacon". Supposedly, anyone who was ever associated with a Hollywood movie can be connected to Kevin Bacon in six "degrees" or less. A degree is a connection, in this case two people appearing in the same movie is one degree/connection.

Consider "The Six Degrees of **MOSAIC**" (or insert *your* favorite complex system here). Using Excel and its easy-to-use organizational chart feature, we started thinking about the connections you could make from MOSAIC to disciplines, then topics, then specific ideas. Each org chart starts with a guiding question: What is MOSAIC? What happens during a typical observation?

The enclosed PowerPoint presentation shows a few levels and a few directions which can be taken with the "Six Degree" idea. One slide shows the parts of MOSAIC, others drill deeper into concepts associated with the instrument. Just about any complex system could become the focal point for a "Connections" game. A handful of carefully chosen systems could form the basis of a semester or year-long inquiry-based, authentic course in any number of disciplines.

More sophisticated software than the org chart tool in Excel is available, including programs for creating higher-level connections using frameworks such as Concept Maps (free download http://www.smartdraw.com/downloads/), Idea Maps, Tree Charts, Mind Maps, or Semantic Webs.

What makes a learning experience authentic? Here are some suggestions[(1)]

Relevance	Students must feel connected to the task, and it has to have meaning to their own lives and experiences. There is a growing "Why do I have to know this?" sentiment among students who are asked to learn science but have no intention of pursuing it as a career. Students rapidly lose interest in "make-work" activities.
Realism	The degree to which a student activity can mirror the methods of a practicing scientist adds realism, which is related to, but slightly different than, relevance. Not all experiments are performed by scientists twisting knobs in the presence of the investigating instrument – use of the internet has spread to include access to instruments around the world.
Uncertainty	The answers to real problems seldom exist in the back of the textbook. Often, the biggest challenge in life is to define the problem before seeking a solution. Giving students an activity which replicates the uncertainty inherent in life's problems can be unsettling, but lends to authenticity. Students have to pay attention if they can't easily predict the outcome.
Adaptability	Out of uncertainty is born adaptability. Scientists must be flexible enough to adapt to changing circumstances. Scientists often begin a project with a proposal to uncover X, only to find intermediate results pushing them in direction Y and Z. Expect the unexpected in scientific research.
Collaboration	All scientific work is done with the help of others. Whether it is bouncing ideas off a colleague or researching previous publications, no scientist sits in isolation waiting to unveil his solitary discovery to the world. The complexity of today's problems requires multi-disciplinary teams to understand the connections among problem constituents before any solutions are possible.
Dedication	In spite of what students learn in the classroom (and on TV), real problems are not solved in an hour. Scientists often spend years of their lives working on many aspects of the same problem.
Outcomes	There should be some form of conclusion to the activity. There may be several intermediate results along the journey, and those results might be subject to interpretation. Large data sets often lead to multiple conclusions. Expect the unexpected.
Reflection	Observations and conclusions must be put into a global context. For a scientist, how do these results affect the body of scientific knowledge? For academic exercises, how did a school activity change the student's world-view?

The excitement we have for Dr. Alan Rogers' MOSAIC system lies in the educational opportunities that fit this "model of authenticity". Think of the serendipitous combination of underlying scientific principles which allows the instrument to reside at ground level and detect the ozone in the Mesosphere, while looking through Stratospheric and Tropospheric ozone:

1. Ozone emits a radio signal at a nominal frequency of 11.072 MHz. This means that if Ozone is present, it will send out a characteristic beacon for all to see.
2. The atmosphere is reasonably transparent at that frequency, meaning a signal from 80 km or higher will reach the ground. The atmosphere is not as forgiving in other frequency domains.
3. Spectral emissions from molecules in a gas undergo pressure broadening. The ozone in lower layers will be spread out over GHz or MHz from nominal, while the ozone in the Mesosphere will be within 20 kHz of nominal. This means that Mesospheric Ozone will leave a sharp peak in a received spectrum, on top of the contributions from lower layers.
4. Satellite TV systems are designed to receive signals in the 10 GHz – 13 GHz frequency range. The basic hardware is very inexpensive (under $50). This means that very little initial cost is required to build an instrument capable of receiving the Ozone frequency.
5. With the addition of a computer, a high-speed digital capture board, and specialized electronics, an instrument could be made for around $3000 which would measure the ozone concentration in the Mesosphere. While slightly expensive for most public schools, this is a tiny cost when compared to the typical multi-million-dollar instrument.

Without a solid knowledge of fundamental principles, Dr. Rogers would not have been able to make the connections which eventually created the MOSAIC system. The "Connection" game acts both as an outline for learning and a model for problem solving. It can be used as a pre-assessment tool to check student understanding of a topic prior to introduction, and then again as a tool to evaluate learning after the unit is completed.

Food for thought: Is the Butterfly Effect just a variant of the Domino Principle? Discuss!

(1) Adapted from Herrington, J., Oliver, R. and Reeves, T. C. (2003). Patterns of engagement in authentic online learning environments. *Australian Journal of Educational Technology*, 19(1), 59-71. http://www.ascilite.org.au/ajet/ajet19/herrington.html