Comprehending the Earth as a system may end up being fundamental to the life of our students in a few decades. With potentially large changes in climate in the future, there will likely be a need to integrate the complex climate responses to anthropogenic influences into the broad framework of interacting spheres (atmosphere, hydrosphere, geosphere and biosphere) that Earth system science (ESS) studies. If this is true, then, what our students really learn from our Earth system science classes will be critical. This places a great responsibility on our shoulders as educators.

ESS education (ESSE) is now in its 15th year of existence, if we count from the start of the USRA ESSE program when a group of active researchers undertook a broad education experiment in a field that was, at the time, in the making. Since that time many ESS instruction experiments have been undertaken at various universities. Often, and not surprisingly due to the complexity and novelty of the discipline, these experiences were done without explicitly structuring classroom experiences based on learning principles. At this juncture ESSE is, I believe, now primed to significantly benefit from recent progress in research on how people learn and how to design classroom environments that optimize learning.

Through my 15 years of teaching Earth System Science, I have explored various ways of teaching it and have become convinced that the Learner-Centered Environment, that builds upon constructivist theory principles and fosters teaching practices that recognize the active roles students must play in their learning, is particularly suitable for Earth system science education. Several characteristics encapsulate how learning is conceptualized from this learner-centered perspective. They include students’ involvement in the material to be learned, students’ acting on the information at a deep level, students’ relating the new material to what they already know, students’ continually checking and updating their understandings based on new experiences, and students’ becoming autonomous learners aware of the learning process. The nature of the knowledge and research environment that characterizes our Earth system science naturally lends itself to the facilitation of student construction of knowledge according to those characteristics mentioned. By providing an active learning experience to students, the LCE effectively offers them both opportunity and motivation to understand this complex area of scientific inquiry and to experience deep, enduring and enjoyable learning. By using a LCE in our classrooms and studying how our students learn in it, we will contribute to the research on learning about a complex science still in the making.

Early on in my career as an Earth system science educator, it became clear to me that ESS learning would greatly benefit from an approach that was centered on students’ learning. After my first grueling experience of ESS teaching, during which I attempted to cover every topic I thought mattered in ESS, I started introducing in my ESS course what I called at the time a "Mini-Rio Summit". In this 2-day activity, students discussed and presented on topics of environment and development that had been highlighted at the Earth Summit in Rio (1992). Their contribution was from the perspective of a representative from a country they had selected as interesting to them. This format encouraged the expression of a variety of viewpoints and provided a more authentic experience. Through this group activity, I noticed how ALL my students became much more engaged in the class, performing extensive research on topics of relevance to their selected country, and displaying originality in their research approach and presentations. This gave me the idea that I should expand on this participatory approach and, unknowingly to me at the time, I started teaching a component of my Earth system science classes using the learner-centered approach. As time progressed it became clear to me that, when students are active participants, their learning is deep, enduring, and enjoyable. As I began to realize that many of LCE characteristics listed above directly map onto quality ESS instruction, I started integrating more and more of these characteristics in my classes.

Through teaching courses that address either the science of climate change or the policy associated with climate change, I have observed my students clearly and effectively constructing their knowledge by gathering and synthesizing information from lectures, books, articles, and from internet research. Two main challenges arose: 1) to guide students through integration of this complex and extensive information and, 2) to coach students through the assessment of information quality when obtained from the internet. The interdisciplinarity of ESS compounds the difficulties of the integration as it often requires input from many different fields. While my knowledge has broadened dramatically over the last 15 years, I have also learned to select the topics we cover in class so that they both provide a comprehensive view of the Earth as a system and are sufficiently familiar to me to teach them with ease. For topics I consider too far from my immediate knowledge (e.g., biochemical cycles) but require inclusion, I often invite guest speakers. This approach ensures that my students learn higher-level science, always drawing on principles and methodologies from the various ESS disciplines. For those topics in which I am marginally knowledgeable, (e.g., ocean thermohaline circulation and climate change), I learn them more in depth every time I teach my class and reflect on their connections with other aspects of ESS. The assessment of information quality represents a more difficult challenge. I address it through a type of cognitive apprenticeship approach that involves both providing general guidelines (e.g., try to assess the author’s reputation, look for the presence and quality of the references), and demonstrating to the students, usually on an individual basis, how to proceed with the quality assessment. This aspect is still work in progress.

As integration of information and making connections are central to ESS, I always ensure that they are performed within the context of critical thinking about contemporary issues and that my students investigate issues from different perspectives (political, geopolitical or intergenerational views) to broaden their
understanding. This emphasis on the development of critical thinking abilities in Earth system science education is especially valuable as it helps students develop a knowledge framework that they can later use as a basis for evaluating scientific evidence for decision-making.

Inquiry-based problem solving approaches are central to my teaching as they facilitate students' involvement in their learning. My students use models to address quantitative questions such as what is the influence of greenhouse gases or aerosols on climate or perform internet research to investigate what potential greenhouse emission limitation can be proposed for a developing country in the context of the Kyoto Protocol. Whether studies of the sensitivity of climate to various external forcing or what if scenarios, targeted inquiries guide my students' learning.

All this is achieved through a collaborative, cooperative and supportive learning environment, where I learn with my students. It always is a joy to see my students actively involved in their own learning, thriving and motivated to explore further topics of interest to them. Their enthusiasm is obvious and so are their initial fears to be facing their peers in presentation settings or to have to choose their own research question for their labs. My personal enthusiasm for the topic and extensive work in preparation to and during the class appears to resonate with students and lead many of them to work hard as they find themselves entrained in the learning process. My TA and I act as coaches who facilitate learning, constantly nudging students to extend their intellectual quest a little more, while providing them enough support (scaffolding) to do it. My teaching is to ensure that students understand and extend themselves. It is no longer limited to covering a specified content.

The evaluation of my students' learning takes place continuously as the learning occurs and is done in partial collaboration with them using a variety of instruments (e.g., discussions, presentations, short web submissions). Under this evaluation paradigm, there is no longer a clear distinction between teaching and assessment. They have become intertwined with the role of assessment ending up being that of promoting and diagnosing learning and no longer limited to grading. The students are always expected to generate better questions and learn from their errors. This is explicit in the rubrics provided for each activity and reinforced in the feedback my TA and I give the students.

The continuous evaluation forces me to exercise flexibility and adjust my teaching to the pace at which the overall class learning proceeds. The pace is sometimes frustratingly slow and often I can't cover all the material I had planned to. Like most instructors, I usually prepare more than I can cover in class and, often times, we deviate from the planned lesson depending on the nature of classroom discussion. What is covered in class varies each time depending on the make up of the class. To me, this is an acceptable solution as, in a broad and rapidly evolving field as ESS, it is impossible for students to learn everything about it in a classroom setting. So, I believe that instruction must provide students with the tools and motivation to study by themselves and become life-long learners who can actively construct their own knowledge during and after class and continue learning long after their schooling has ended.

One issue the students and I continuously grapple with is that of uncertainty. As uncertainty pervades many of the dimensions of Earth system science, students need to be aware of it, of its origin and its implications. This is an area of active research and one with which I do not expect my students to have much experience. I often have them reflect about uncertainty in the classroom setting and discuss various aspects of it, and in particular, how we can account for it in the policy decision process. Addressing this issue collectively hopefully helps students be more comfortable with dealing with doubt and uncertainty that exist in their lives.

Finally, I find the learner-centered approach to be particularly suited to the heterogeneous student body of most of my classes. The integration of new information with students' current understanding is particularly suited to the heterogeneous student body of ESS students who generally come from a broad array of scientific disciplines (sometimes pre-law, political science or English). Each student's knowledge and contribution is thus valued and integrated in the overall classroom learning.

In summary, based on my personal experience, I am convinced that Earth system science instructors need to move away from designing courses driven mostly by content, delivered through lectures and punctuated by objective tests towards courses centered on specific learning outcomes, based on the principles of learning, and guided by what students bring to the class-room. Accepting the challenge of designing a learner-centered environment for our classes means revising our traditional ways of teaching and becoming facilitators of student learning. We must plan and design classroom activities to assist students' learning, and join them in the life-long learning enterprise. The learner-centered way of teaching is demanding and time consuming. It requires more planning than a conventional way of delivering material and the design and delivery need particular attention. It can be a process of trial and error at the beginning. It may therefore appear to be too taxing in an early faculty career. It is, however, well worth the efforts in the long run as our contribution will deepen students' understanding of the field and prepare them to be informed citizens of this complex world. And, along the way, we will enjoy the teaching experience immensely and be amazed by the learning our students display.