Transforming Learning in Astro 101: Using Spatial Curricula to Teach Spatial Concepts

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Every year in the U.S., a quarter of a million college students take an Astro 101 course. 40% of all pre-service elementary and middle school teachers take such a course, with the majority indicating that Astro 101 stands as the last formal science course of their education. For many non-science majors, college level astronomy represents their last chance to learn about the body of scientific knowledge, the ways in which scientists model concepts, and the processes by which scientific knowledge is generated. Sadly, a large body of research indicates that these students will leave their Astro 101 course with little better understanding of the earth and universe than when they entered the course, indeed, with little better understanding than they had when they were in elementary school. This reality is troubling, considering that many of these same students go on to teach in elementary and middle school classrooms, where astronomy makes up a large part of standards-based instruction. It is therefore no exaggeration to state that an ineffectively taught Astro 101 course will likely result in poor primary school instruction. This gives us very good cause to find ways to improve our instructional practices at the college level.

The research work I share with my collaborators and our collective cadre of graduate students is largely concerned with the cognitive barriers that exist to students developing scientifically accurate conceptions in astronomy, and the ways in which our research findings can improve the effectiveness of our instruction. Given that instruction in the most reformed of classrooms results in students continuing to fail our domain’s test of basic astronomical knowledge, we have little hope that the research lines of the past are going to help us. Instead, our work has turned to looking at difficult concepts to define the specific nature of the learning roadblock, whether that be some kind of phenomenological primitive, an issue of identity or belief, or most often in astronomy, a roadblock related to spatial thinking. Given our first wave of findings, we have begun developing inexpensive, easy-to-use curricula that support, or act in lieu of students’ abilities to think spatially. While the majority of Astro 101 instructors would reject the idea of explicit spatial training in their courses, the idea of improving instruction with support for spatial thinking appears to be reasonably palatable. While we have no evidence that such Astro 101 instruction improves spatial thinking in a generalizable sense, data do suggest that these instructional interventions allow students to understand astronomical concepts that have eluded them for most of their formal education.

My comments here briefly describe our group’s work in three parts:

- Establishing the underlying mechanism for the most robust misconceptions in astronomy,
• Developing curriculum that supports or replaces spatial reasoning for concepts in which spatial thinking forms the major barrier to learning,
• Crafting protocols for a systematic research agenda focused on the previous two tasks.

Moon phases, seasons, and the Big Bang; or "Why can’t they learn this stuff?"
Each of the science domains has at least a short list of misconceptions that appear to be unyielding in the face of typical instructional strategies, but in the field of astronomy and the space sciences, we think that we have more than our fair share. Even after a college level astronomy course, the average student cannot score better than a 50% on the TOAST (Test Of Astronomy STandards), an instrument constructed to assess learning of what is considered basic K-12 astronomy knowledge. Student understanding of the Big Bang, the structure of the universe, the causes of the seasons or of the moon phases, the Doppler shift, and the expansion of the cosmos does not occur, even in the face of constructivist and conceptual change teaching strategies. This failure in the educational process is well documented, although the cause of the failure is not.

Our initial investigations into the cause of our instructional failures has been influenced by the existing body of literature which indicates that, for some of these difficult ideas, maturity, educational opportunities, gender and culture are not important variables in influencing conceptual understanding. Rather, as we saw in A Private Universe, there is something about the human brain that simply does not like to think about the cause of Earth’s seasons, for instance, in a scientifically accurate way, and that the preferred manner of thinking varies little between an 14-year-old, middle class girl with an 8th grade education, and a fifty-something, upper middle class, PhD-bearing full professor at the world’s most prestigious institution of higher learning. We find this equity, across so many important education variables, to be nothing short of shocking, and a clear signal that if we are to craft improvements in instruction, we have to start thinking about the influence of cognitive structures. Moreover, we must do so at the level of the specific astronomical concept.

We assert that there are perhaps four primary barriers to learning astronomy, that are completely unrelated to traditional predictors of educational achievement (e.g.: access to good schools, socioeconomic status), and that spatial thinking is the greatest of these barriers to understanding astronomical concepts. However, we believe that spatial thinking is important for some aspects of astronomy and not for others, and that the impact of spatial thinking to learning cannot be deduced simply by reviewing the surface features of the task, or by performing a traditional rational task analysis. Our first forays into determining the role of spatial thinking in Astro 101 indicates that in some cases, those concepts that appear to rely on spatial thinking, such as the structure of the universe or that cause of day and night, do in fact rely on spatial thinking. In other cases, such as the case of the Big Bang, spatial thinking seems to have little impact on learning, even though the concept is the ultimate example of the expansion of matter and space. In recent work looking across the breadth of the Astro 101 domain, we observed that overall astronomy knowledge and students’ knowledge gains, are correlated to some measures
of spatial thinking, but they are not highly correlated with students’ course grades, majors, or
genral academic success, and that the correlations for individual concepts vary widely.
Considered collectively, the work we have done thus far represents the bulk of research into
spatial reasoning in college level astronomy, and that work is very nascent. We are currently
taking on this problem in rather broad swipes, but the work is promising, and is already resulting
in a few very effective instructional interventions for the Astro 101 classroom.

**Changing the Way We Teach Astro 101.**
Having some indication of the places in which spatial thinking influences learning of astronomy
concepts, we’ve turned part of our attention to developing or adopting pragmatic instructional
strategies that support the student as they attempt thought processes that rely on spatial
abilities. In our reiterative research model, we empirically examine the interventions in light of
their potential to move students toward scientifically accurate and generative conceptions. With
regard to astronomical geography, orbit-related, and tilt-related phenomenon, the data suggest
that a curriculum that supports, or acts in lieu of a student’s spatial thinking, can transform their
understanding of the content, in a very short amount of time, and in conditions in which
traditional and reformed teaching practices have already failed. Early data indicate that this is
also true for a newly developed curriculum related to the structure of the solar system. In both
cases these interventions have been successful with a variety of students, including those who
are underrepresented and those who were considered “at-risk” of failing to do well in the course
(e.g.: second language learners). This work indicates that some of the more robust
misconceptions in Astro 101 can be overcome by matching instruction to the specific cognitive
barriers that block student understanding, including the barrier of spatial thinking.

**A Systematic Approach to Understanding Spatial Thinking in Astro 101.**
Our intention is to tease out the role of spatial reasoning in Astro 101, one concept at a time. We
are now in the process of investigating those ideas that we know to be recalcitrant in the face of
all currently used methods of instruction: issues largely related to the celestial sphere, and to
astronomy’s unique sense of time and scale. For the majority of these concepts, we hold the
existing assessments somewhat suspect, necessitating the construction of new instruments that
validly measure student understanding, but which are not biased by working memory or verbal
ability. For each concept we are attempting to determine the specific nature of the spatial
reasoning difficulty, (e.g., visualization, transformation, environmental reasoning) in order to
tightly tailor instruction.

My goal in attending the specialist meeting is two-fold. First, I am hopeful that I might gain
insight in to the frameworks and instruments being used in other disciplines so that we might
parallel that work to the extent possible. Such commonalities should naturally facilitate
communication and cross-disciplinary comparisons. Second, I hope to discover pathways that
promote communication and collaboration between the discipline-based researchers in the
sciences, and the spatial thinking researchers within the human sciences.