Symmetry and Aesthetics in Contemporary Physics: An Interdisciplinary Arts and Physics Curriculum

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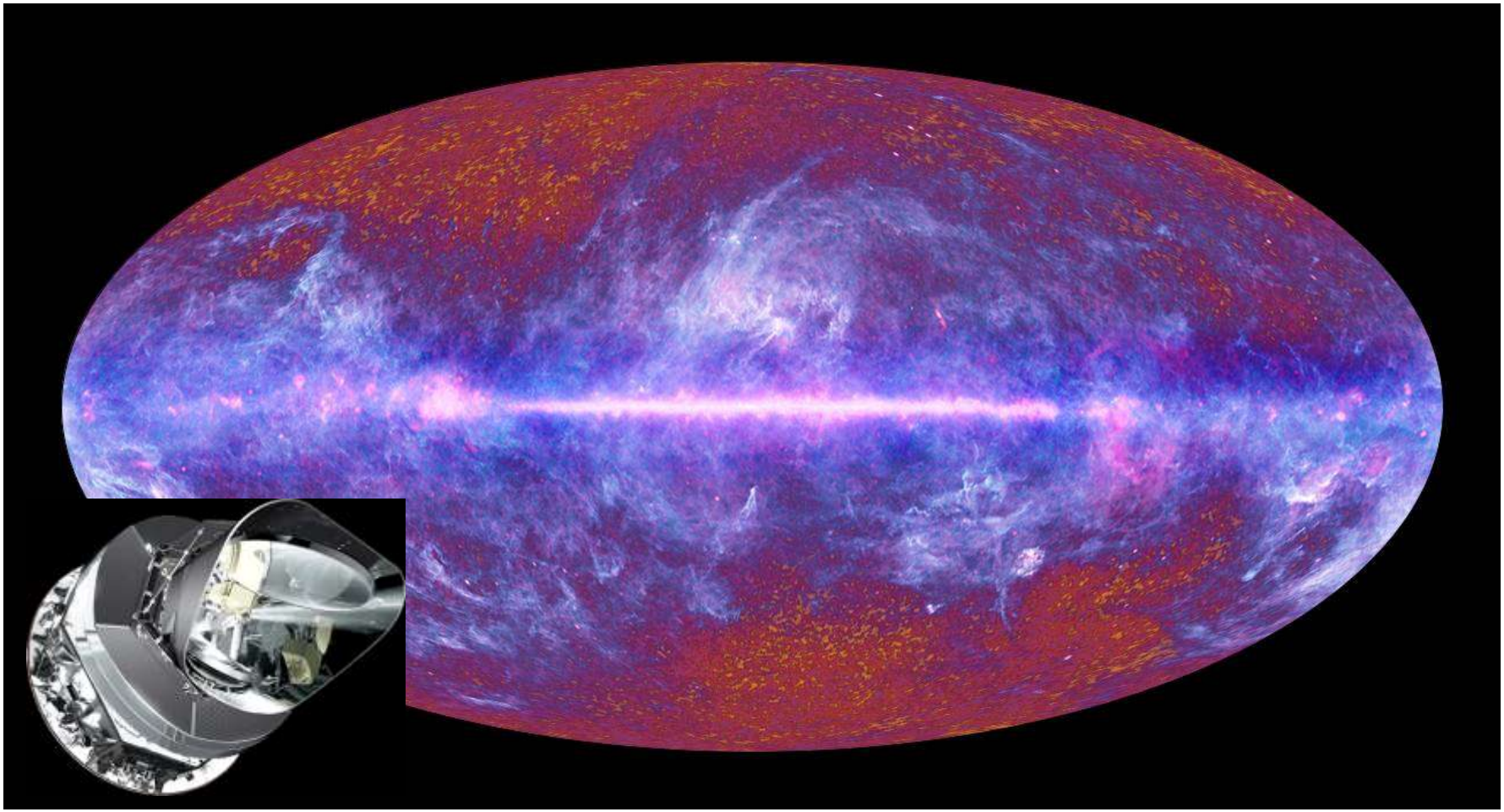
Women in Physics Symposium, University of Oregon, 16 April, 2011

The Planck Mission

PLANCK Education and Public Outreach

Planck is a Mission led by the European Space Agency, with significant participation by NASA, the purpose of which is to map the Cosmic Microwave Background (CMB) with a sensitivity of a few millionths of a degree Kelvin, and an angular resolution as fine as 5 arc minutes on the sky.



Education and Public Outreach Group, Planck Mission, NASA:

Purdue-Calumet, VisLab
Lead Application Developers:
Jerry Dekker, Lead Programmer
John "Jack" Moreland, Visualization Specialist

University of California, Santa Barbara:

Department of Physics
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Evelyn Alfago, Blake Regalia, undergrads

UCSB AlloSphere
JoAnn Kuchera-Morin, AlloSphere Director
Ryan McGee, Basak Alper, Wesley Smith
Ph.D. candidates in Media Arts Technology

Lead P.I., Planck Visualization Project: Jatila van der Veen
Planck Project Scientist and Lead Principal Investigator at NASA/JPL: Charles R. Lawrence

Planck Launch: May 14, 2009
photo: Charles R. Lawrence

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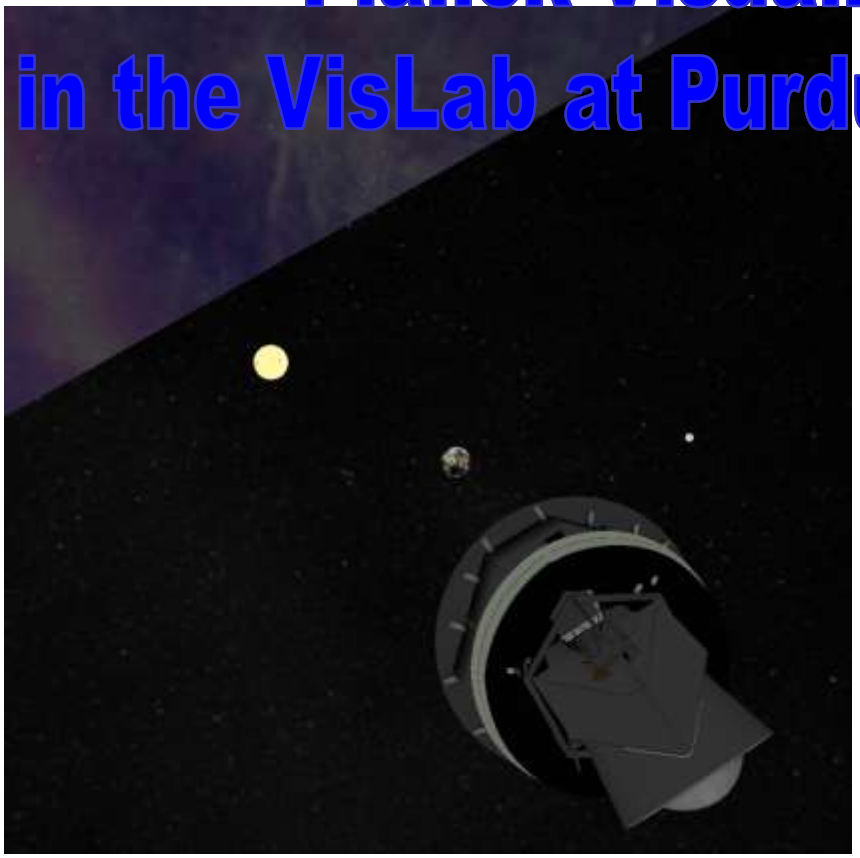
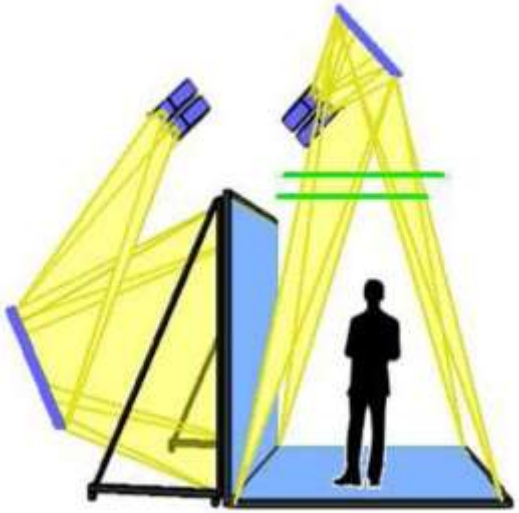
Planck Visualization Project in the VisLab at Purdue University Calumet



PI: van der Veen (UC Santa Barbara); Graduate students John (“Jack”) Moreland and Gerald Dekker (Purdue University Calumet)

(See Dekker, Moreland, and van der Veen, *in prep*.)



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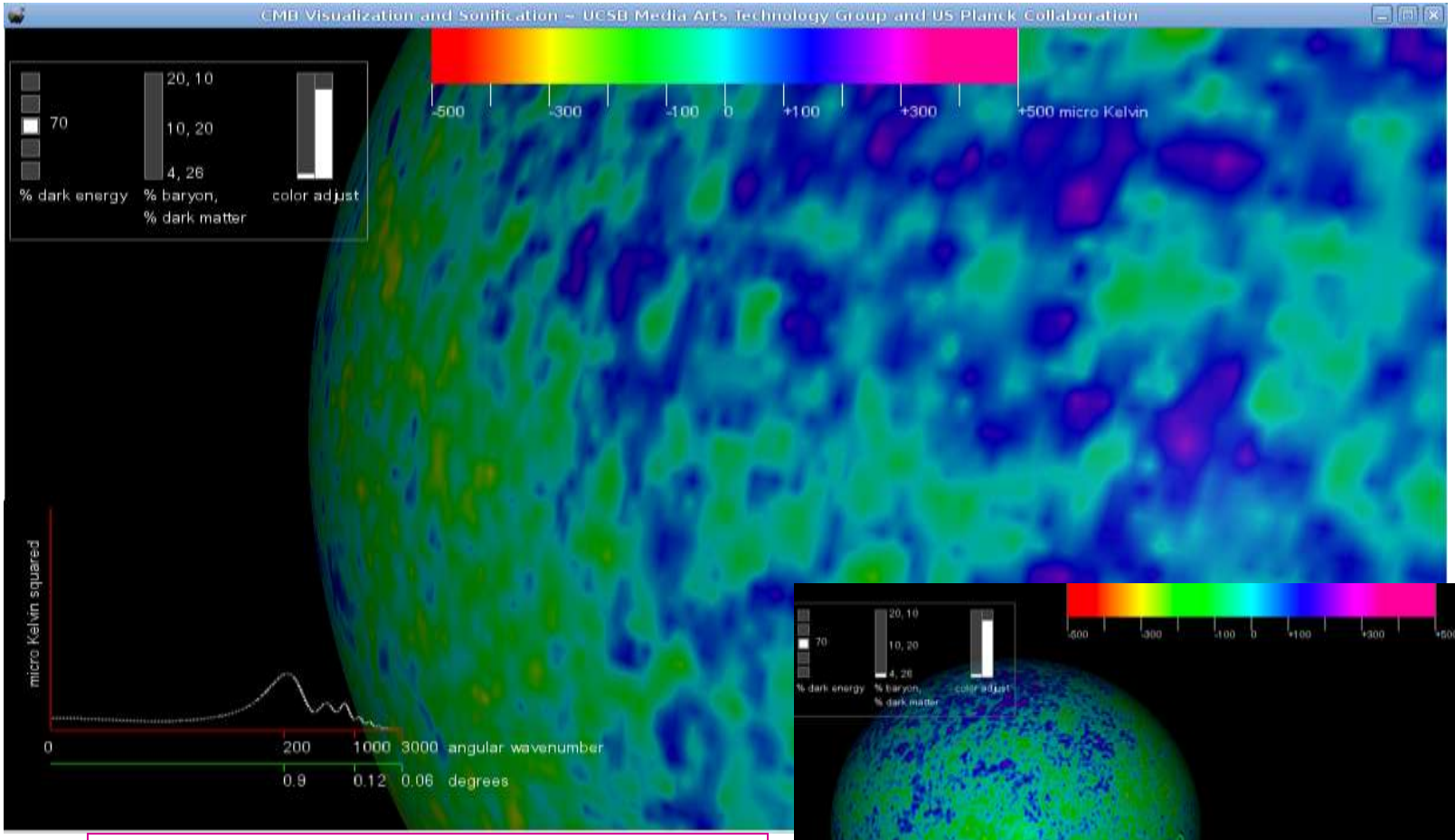
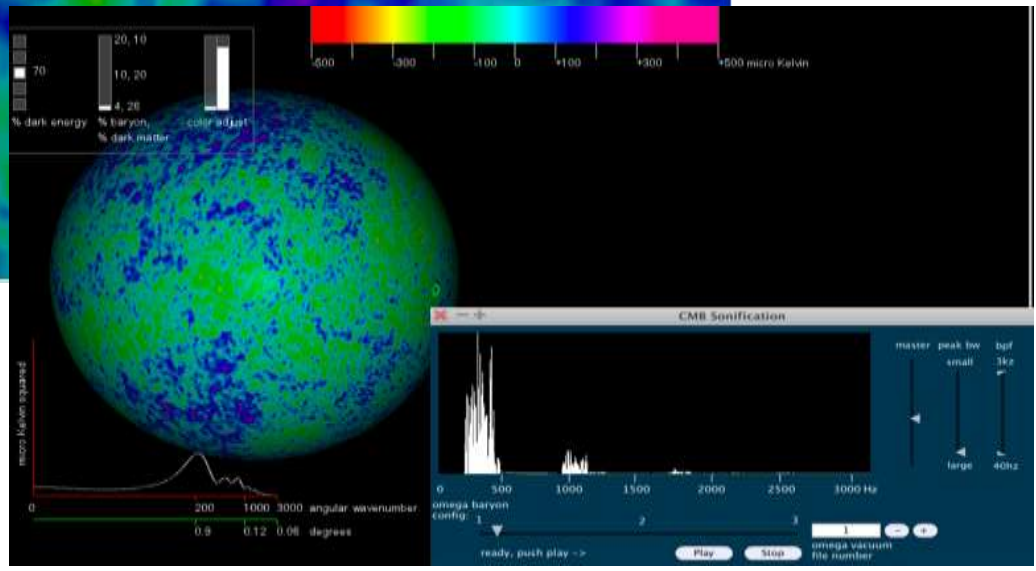
Visualization and Sonification of the CMB in the AlloSphere





PI: van der Veen; Collaborators: Lubin, Kuchera-Morin; Graduate students Ryan McGee, Basak Alper, Wesley Smith, all at UC Santa Barbara

The AlloSphere at U.C. Santa Barbara

… a total immersion laboratory / microscope for multimodal representations of multidimensional data sets.

Founder / director / inventor:
Professor JoAnn Kuchera-Morin

See www.allosphere.ucsb.edu

Symmetry and Aesthetics in Contemporary Physics: A new paradigm for introductory physics

1. The Problem, the Question, and the Intervention
2. Cognitive Basis for teaching physics with arts
3. Definition of Aesthetic Education
4. The Course – topics and assignments, samples of students' work
5. Evaluations, reactions, metrics…
6. Summary/Conclusion: 10 Strategies for Success
7. Potential applications in K-12 and Teacher Preparation

1. The Problem:

"For most men, save the scientific workers, science is a mystery in the hands of initiates, who have become adepts in virtue of following ritualistic ceremonies from which the profane herd is excluded".

John Dewey, *The Public and its Problems*, 1927

… Children grow up learning that science is scary and – especially physics and math. Somehow, chemistry doesn't have that big of a stigma, but physics and math – it's like, Oooo, Scary. …

I think there's just something that is DONE in the way that it is arranged or taught that makes people really AFRAID of it, and I think it is taught in a way that is kind of – seems very EXCLUSIVE. And I ALWAYS had that feeling about physics, I always had the feeling that scientists are exclusive…

Female sculpture major in the College of Creative Studies, UCSB, Spring, 2007

Numerous studies have addressed fear of physics.

From Schibeci, R. A.(**1984**) 'Attitudes to Science: an update', Studies in Science Education, 11: 1, 26 — 59:

'Science anxiety is a phenomenon of national scope that is well known but little understood. Like its relative, math anxiety, it paralyses students (especially women and disadvantaged minorities).'

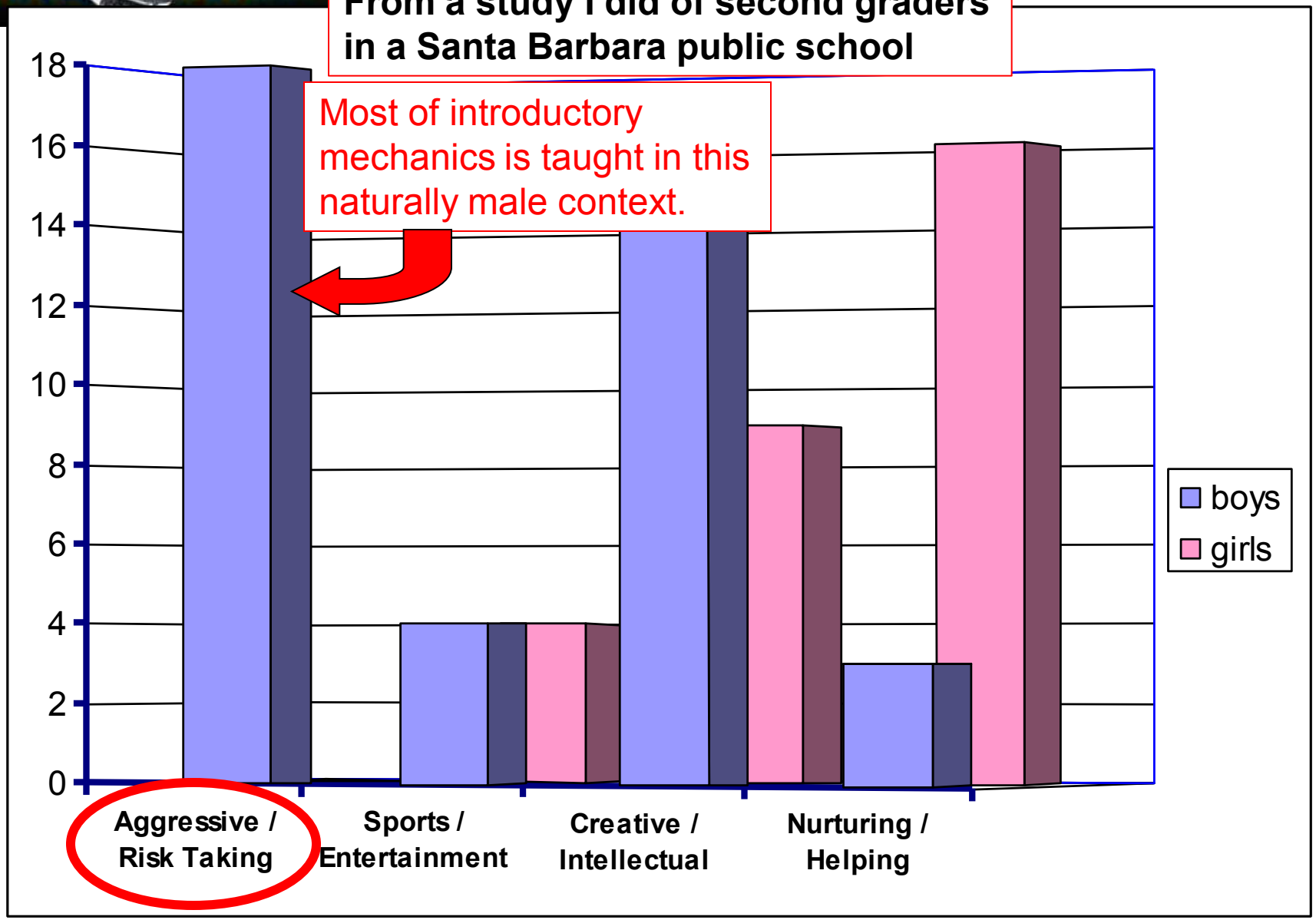
gender

'Sex is probably the single most important variable related to pupils' attitudes to science.' … and they go on to cite 25 studies.

'The physical sciences [are] viewed as more masculine career fields than the biological science by both boys and girls.'

From a study I did of second graders in a Santa Barbara public school

Most of introductory mechanics is taught in this naturally male context.



Numerous studies have addressed gender issues in physics.

From Brotman, J.S. and Moore, F.M. (2008) Girls and Science: A Review of Four Themes in the Science Education Literature, JRST VOL. 45, NO. 9, PP. 971–1002 (2008):

pre-1990's: deficit model = there is something wrong, but the fault lies with the girls

1990's: equity and access model = there is something lacking with school science

This prompted a move toward more critical, feminist, and "emancipatory" theoretical frameworks in science education.

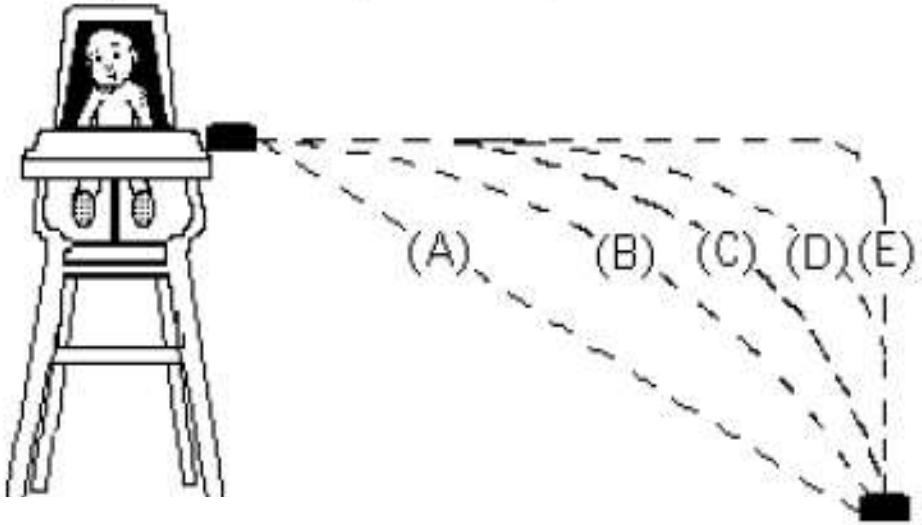
~2000's: shift towards studies of nature & culture of science and developing science identities

In her book Beamtimes and Lifetimes (1988), anthropologist Sharon Traweek of UCLA calls physics
"a certain kind of privileged knowledge, a way of knowing that is profoundly gendered and cultural ."

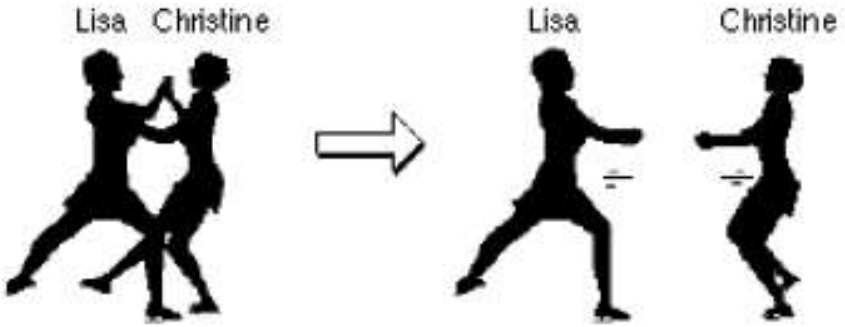
The cultural bias of Western philosophy, communicated through language and metaphor, as well as history and practice, has made science and technology virtually synonymous with masculinity.
(Karen Zuga, 1999, Journal of Technology Education).

"Feminizing" the FCI ???

12. A baby in a high chair slides her bowl of food horizontally off the side of her flat tray with a quick push. Which path below best represents the path of the bowl?



28. Two figure skaters, Lisa who has a mass of 95 kg and Christine who has a mass of 77 kg, are standing on the ice with Lisa's hands braced against Christine. Lisa suddenly pushes off of Christine, causing them both to move.



Female version of the FCI – Laura McCullogh, Wisconsin

The problem still remains.

Although by certain measures progress has been made over the last 30 years in narrowing the ‘‘gender gap’’ in science, girls and women continue to be underrepresented and marginalized in fields such as physics, engineering, and technology (American Association of University Women [AAUW, 1998]; Brickhouse, 2001; Fadigan & Hammrich, 2004; Gilbert & Calvert, 2003; Scantlebury & Baker, 2007).

“A focus only on gender, which is usually narrowly based on heterosexuality, and a lack of consideration of other power relations based on ethnicity or class, tends to mask complexity.”

Hughes, G.(2001) 'Exploring the Availability of Student Scientist Identities within Curriculum Discourse: An anti-essentialist approach to gender-inclusive science', Gender and Education, 13: 3, 275 — 290.

ROSE

From the Relevance of Science Education project in Europe, 2007:

Interest profile (108 items!):

- **In poor countries:**
  Pupils want to learn about 'everything'
- **In richer countries:**
  Pupils are more selective, and strongly gendered profile:
- Traditional school science' at the bottom
- **Girls:** biology and health,
- **Boys:** Explosives, engines, machines
- **Top priority for both:**
  The philosophical, the unsolved mysteries, space science…

The Question:

How can we make physics accessible to a diverse population of learners in a way which is:

- **gender-neutral,**
- **culturally responsive,**
- **utilizes multiple learning strategies,**
- **contemporary,**
- **not intimidating yet which does not 'skimp' on the math,**
- **adaptable to a range of ages and ability levels,**

and provides a basis for all students to enter into a dialog with physics?

The Intervention:
A new paradigm for physics education

An interdisciplinary physics curriculum based on Symmetry as the mathematical foundation of physics as well as the motivating principle in the arts

and which utilizes visualizations, drawing, and music, along with mathematics, in teaching foundations of contemporary physics, starting from the perspective of symmetry.

Symmetry and Aesthetics in Contemporary Physics

From van der Veen (2007) : ☺

New approach to the issue of access to physics: Instead of male/female, majority/minority, treat Arts and Sciences as the "two cultures" (Eisner, 2000).

In my work with college students, I find that the arts vs. sciences two-cultures model cuts across gender and racial boundaries.

Start from a topic that is 'gender neutral' and contemporary.

Start with symmetry and the contemporary view of spacetime; include cognitive strategies from the arts along with math.

"The study of space and time is rooted in the complex of a world view, in which beliefs of different nature are mixed together. …[and] give sense and cultural value to physics formalism." (Olivia Levrini, 2002)

2. Psychological – Cognitive - Educational Basis

Psychology: **Howard Gardner ~ *Multiple intelligence theory***
Mihalyi Czikczentmihalyi ~ *Psychology of Creativity*
Vera John-Steiner ~ *Languages of the mind*

Cognitive Neuroscience: **Michael Gazzaniga, UCSB, and others:**
fMRI studies reveal areas in the brain that are involved in language, music, spatial reasoning, and logic overlap

Education: **Swiss Education Reformer Johann Heinrich Pestalozzi (1746 – 1827)**

Anschauung: mental imagery developed by abstraction from phenomena, which have been directly experienced – learning is based on visualization, numeration, and verbal description

American Education Theorists John Dewey, Maxine Greene, Elliot Eisner

Three design features of this curriculum:

1) Contemporary Perspective: *"Noether before Newton"*

Start with Symmetry, discuss Math as a Way of Knowing; Put Relativity First, then go back to Newton from the contemporary point of view.

2) Aesthetic Approach: Math and Art are both languages of nature

3) Interdisciplinary Strategies:

Critique literary works by theoretical physicists;
Have students draw their understanding of physics concepts;
Utilize lots of group work, class discussions, student presentations;
Utilize music and art to teach concepts in math that support the learning of physics.

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Noether's Principle:

Continuous symmetries in Nature are the basis for Conservation Laws in Physics.

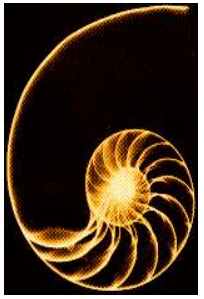
…an opportunity to foreground the woman whose math paved the way for contemporary fundamental physics!

Dr. Noether's mathematics provided the proof that General Relativity is a viable theorem, and is the motivation for all fundamental physics beyond the Standard Model (Supersymmetry, String Theory, dark matter searches, etc.)

Yet most people have never heard of her!

Changing the physics folklore is one of THE most powerful ways of changing the physics community.

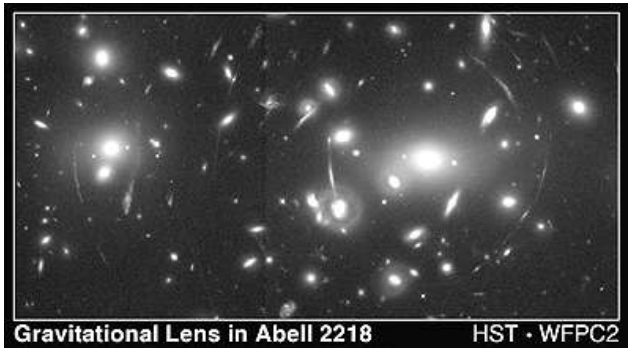
4. The Course: topics…



1. What is Reality, What is Physics, and How do we know stuff?
2. Math as a Language and a Way of Knowing and Seeing
3. Symmetry – Definition, Rotation matrices, Intro. to Group Theory, Applications in Physical Laws and in Art

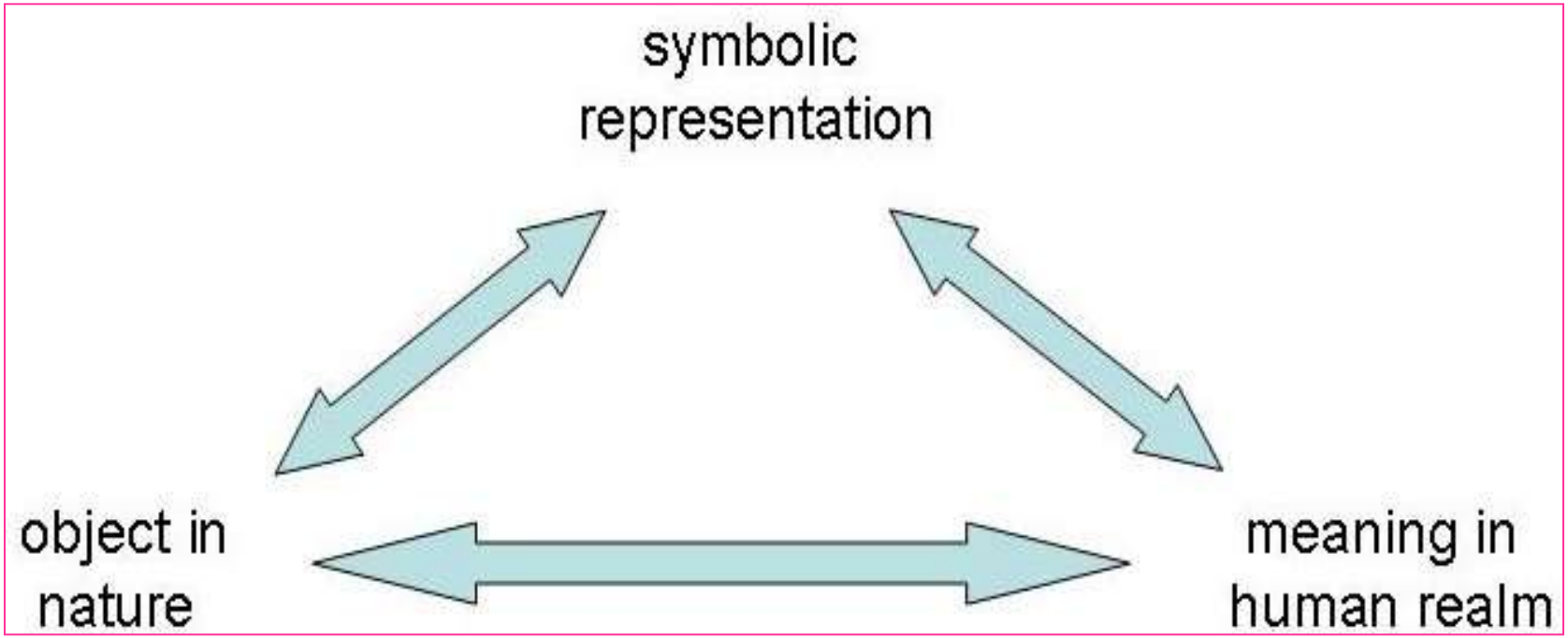
4. Intro to Special Relativity

5. Principle of Least Action
6. Intro to General Relativity and Cosmology
7. The Unreasonable Power of Math



Introductory topic: Start with metacognitive reasoning.

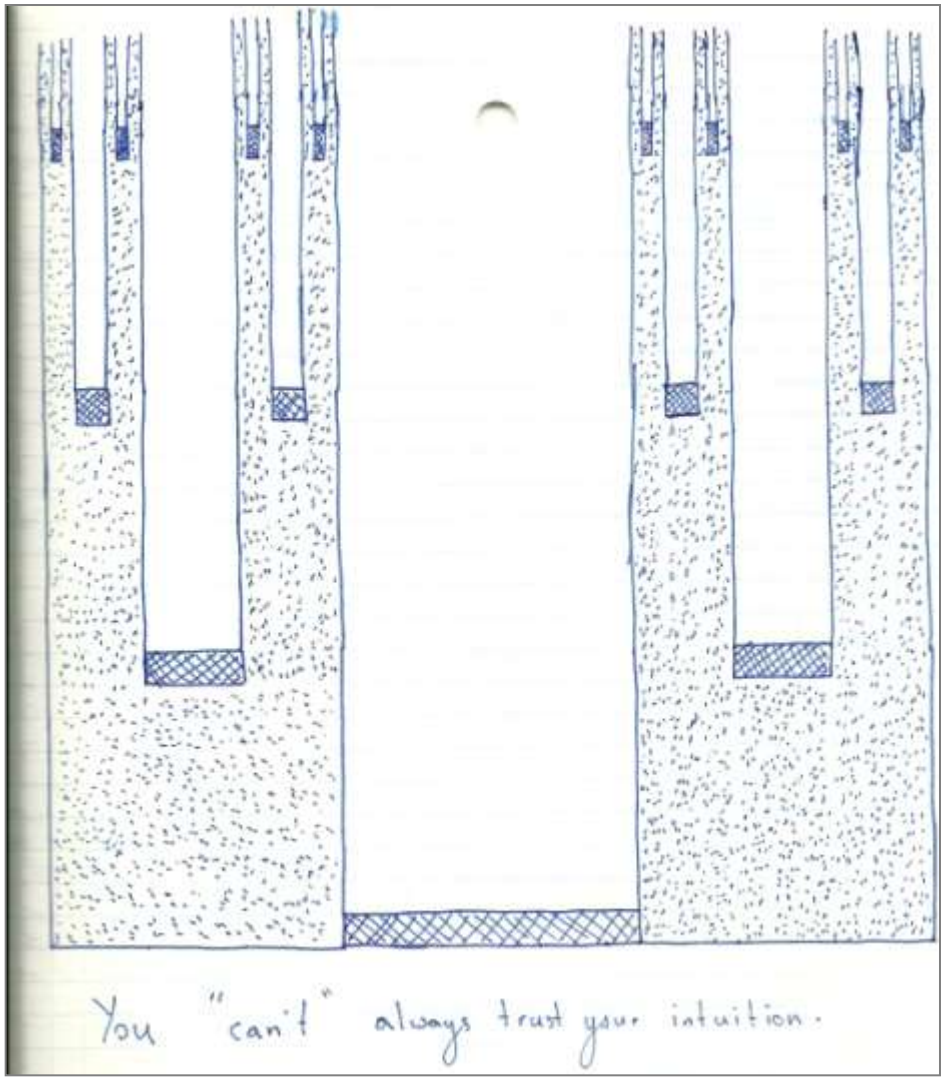
- *Semiotics: the study of signs and symbols*



First Einstein Drawing Assignment

1. Nature of Science Reading: *Physics and Reality* by Einstein (1936)

a) Critique this article
b) Draw your understanding of this article



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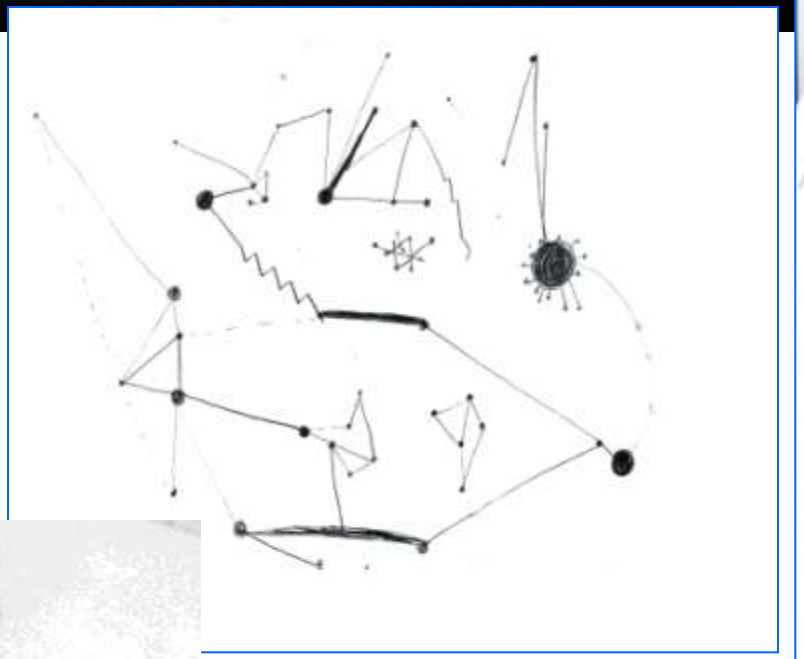

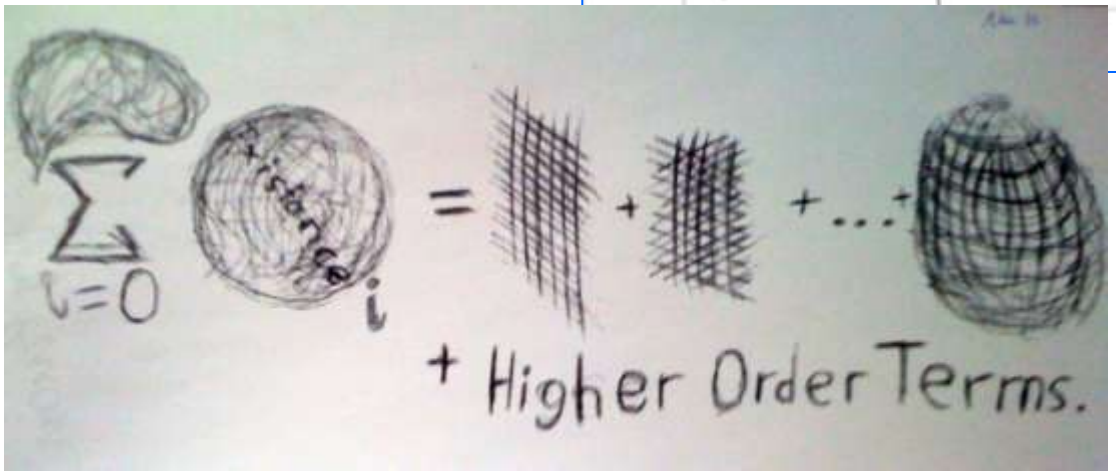

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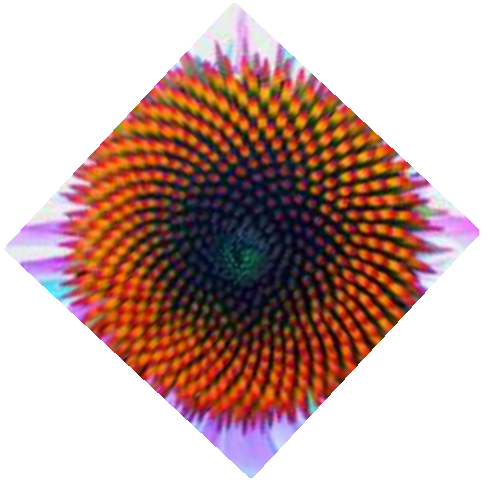

2. Introduction to Mathematical Reasoning

Is the universe mathematical ?

Or is it just our perception ?

We start with the example of ϕ - an accidental discovery – and show how it shows up in so many natural systems.

Sample discussion:

Mario Livio

Lawrence Krauss

Two different theoretical physicists discuss numbers in nature.

Writing assignment / discussion:

** How would you characterize each one's approach to numbers in the natural world?

** Which one do you 'resonate' with more? Why?

Sample responses from homework essays:

from an RR comparing Krauss and Livio by a 4th year sculpture major:
Both present essentially physics-related ideas and aim that presentation at essentially non-physicists. I as a non physicist, find Livio a lot easier and more engaging to read.

from an RR about Krauss, "The Art of Numbers" from Fear of Physics, by 3rd year biology major:

My second and third year calculus teacher in high school used to say that math was the language of love. Somewhere along the way, working on a particularly challenging problem set, I stopped feeling the love. … This article made me realize how much I really do love math still, because as my dad always reminded me, it's the same anywhere and it does not lie. It's perfect as the language of love.

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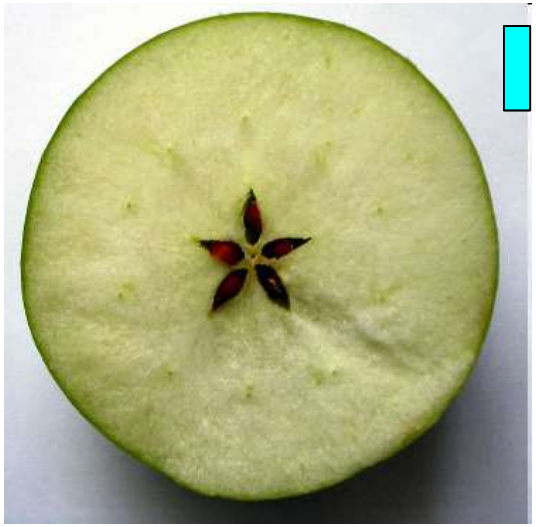
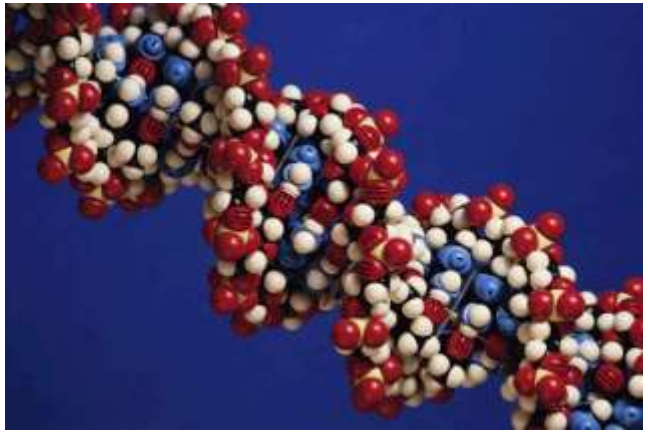
Introduction to Symmetry



Class 4 , CCS-120
Symmetry and Aesthetics in Contemporary Physics
Professor Jatila van der Veen

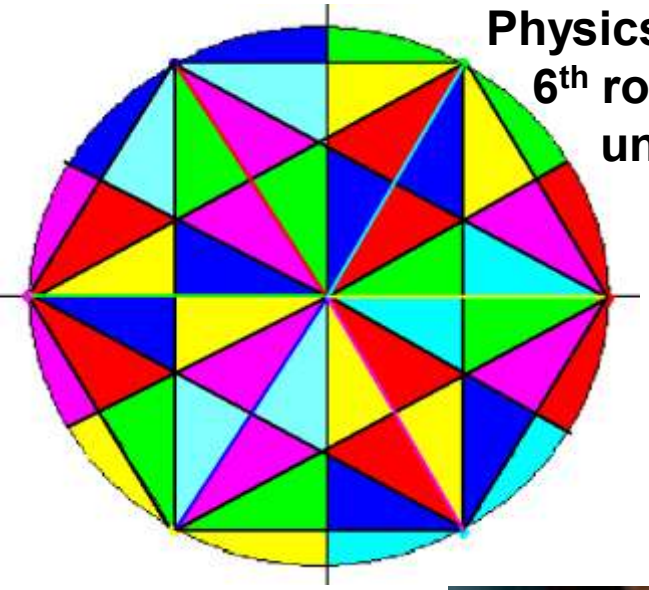
Reading: Feynman, Symmetry in Physical Laws



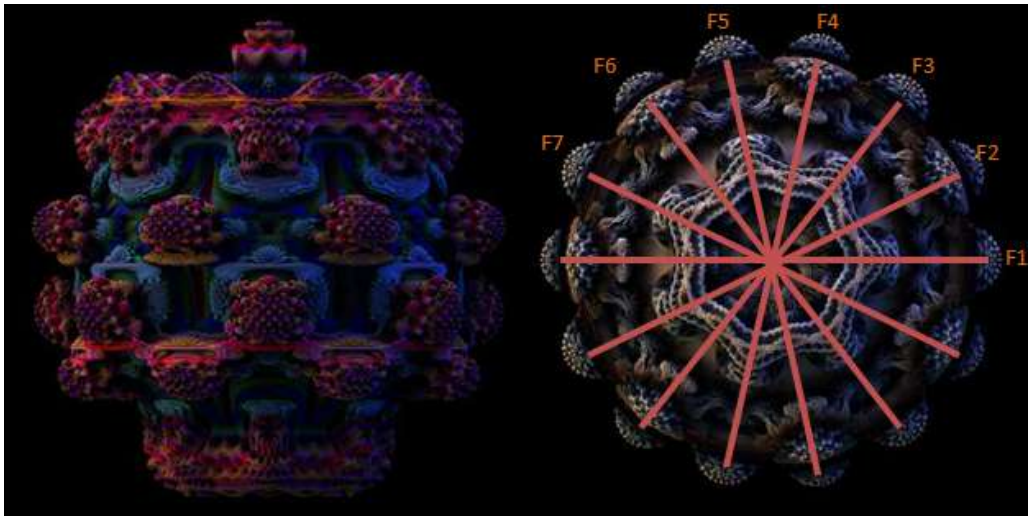
Symmetry

Broken symmetry!

Examples of students' symmetry demonstrations:



Physics major: 6th roots of unity



Physics major: Symmetry of the Mandelbulb

Art major: D_3 becomes SO(2) when spun with a battery-operated motor!

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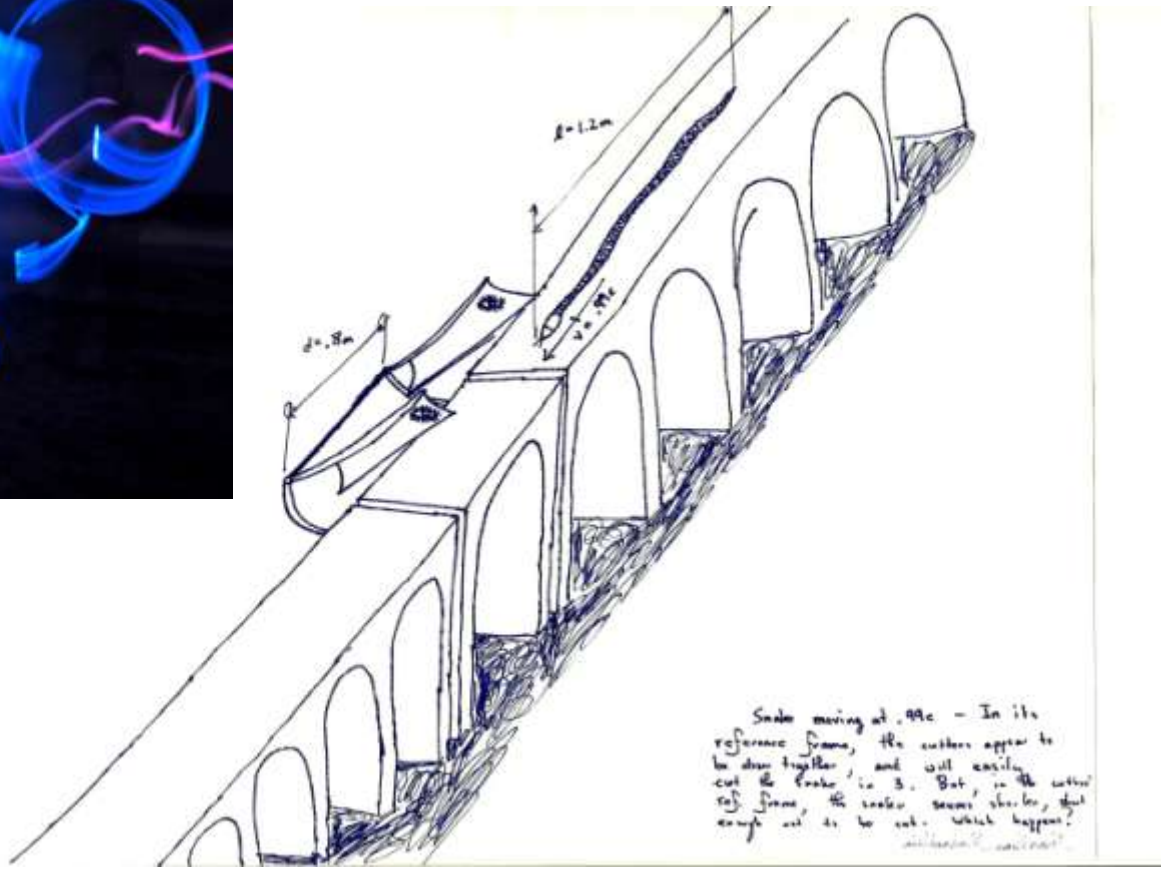
Introduction to the Theory of Special Relativity: A Fundamental Symmetry of Spacetime

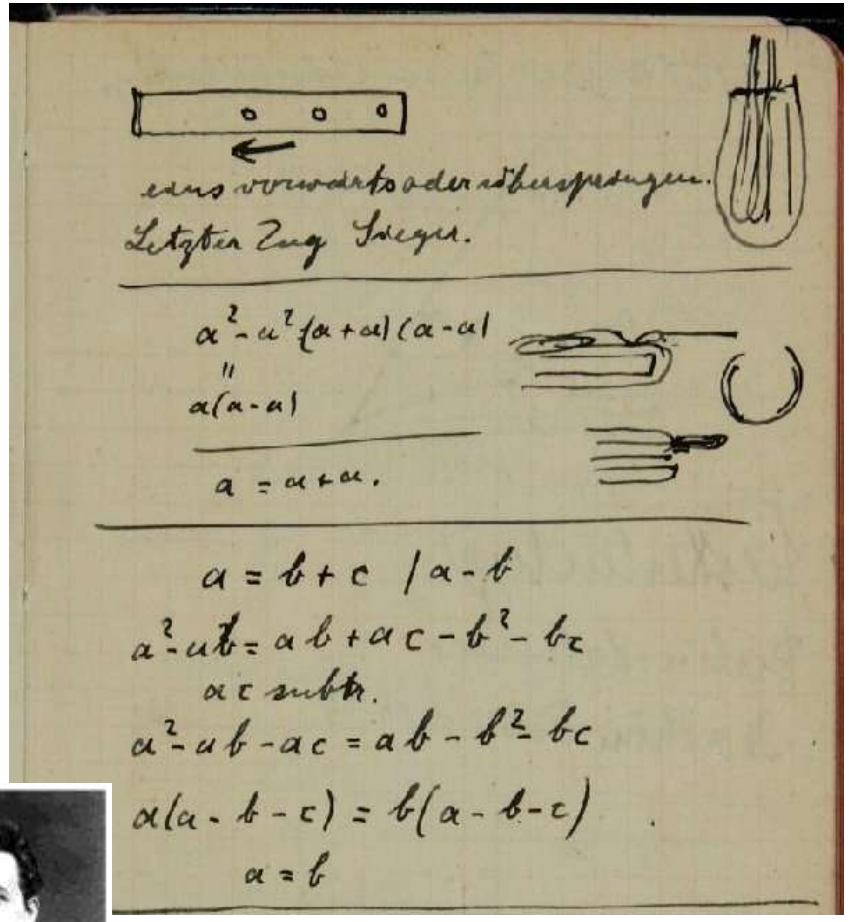
CCS-120
Class 6
Professor van der Veen

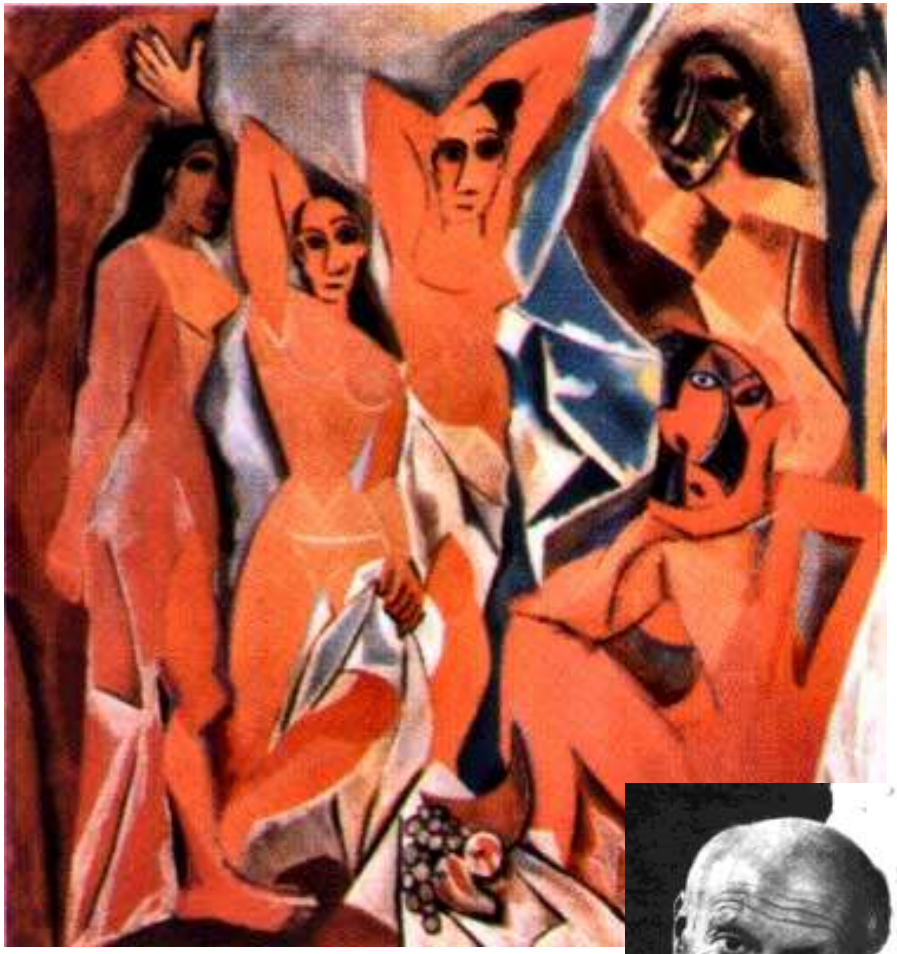
Second Einstein Drawing: visualizations of the problem of simultaneity



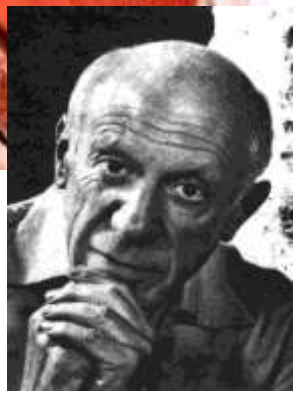
Reading: Einstein, Picasso by Arthur Miller – an exploration of Special Relativity in the Science and Art of the early 20th Century.

Example: Les Demoiselles d'Avignon





Einstein, ... Picasso



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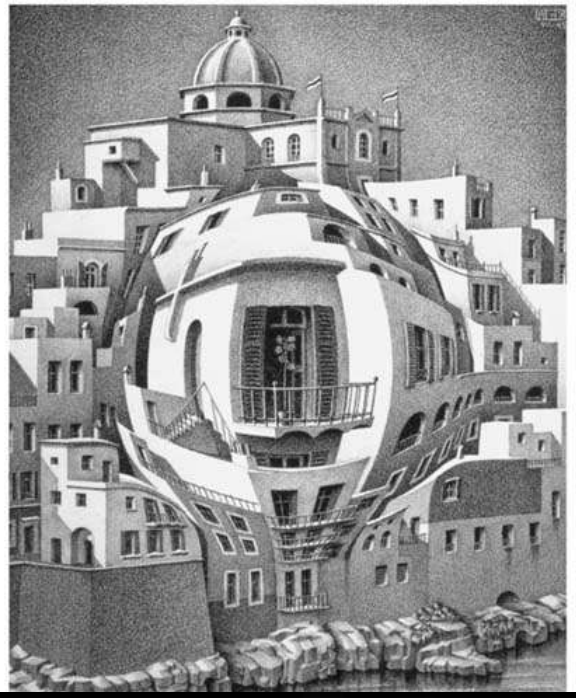
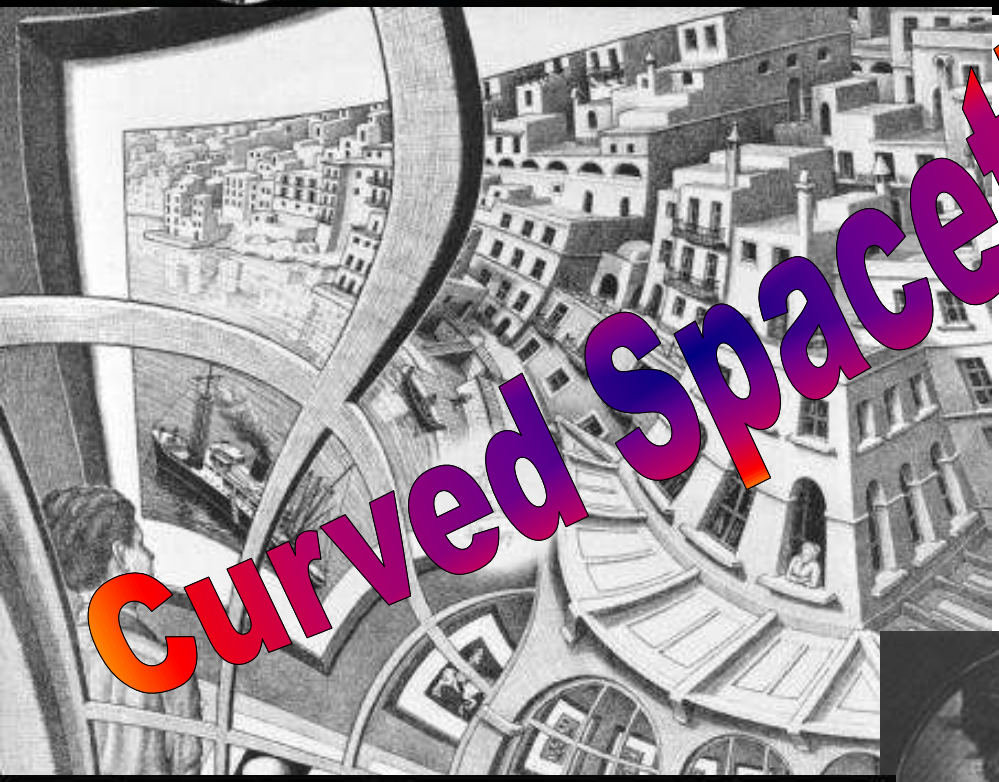
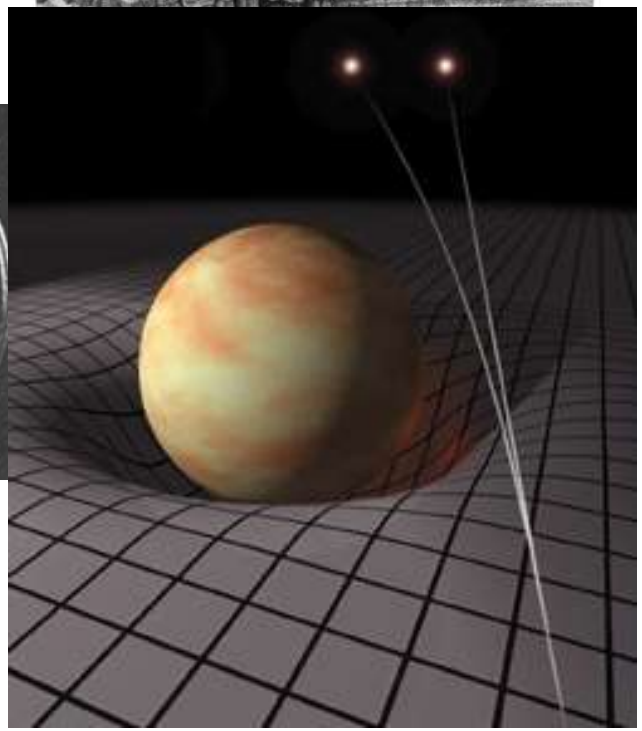
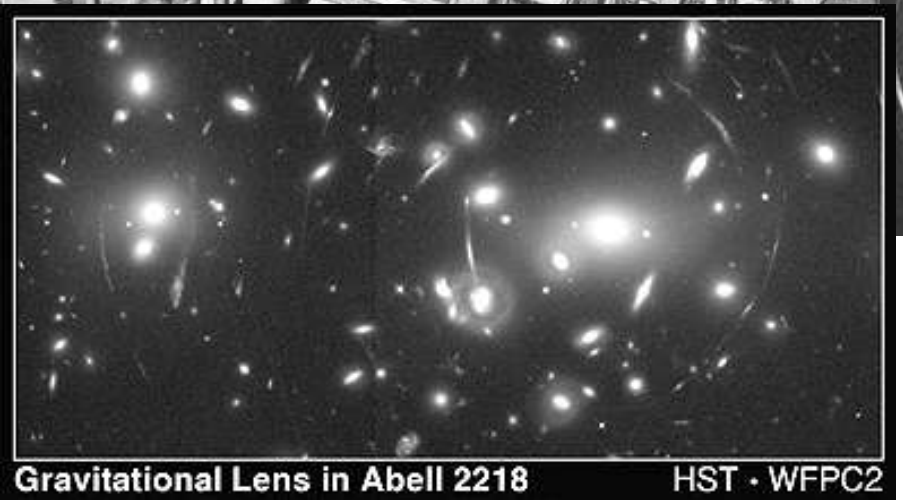
Curved Spacetime









Gravitational Lens in Abell 2218 HST · WFPC2

CCS-120
final topic

Weekly reading / writing assignments

Introducing students to Physics Discourse by reading the words of the masters and interacting with them through literary dialog

* Albert Einstein
* Richard Feynman
* David Gross
* Stephen Weinberg
* Mario Livio
* Tony Zee
* Lawrence Krauss

… among others…

Students get to know real physicists through their literary works.

from an RR by a 3rd year painting major, female:

Weinberg then assesses that "Einstein's theory is nothing but an approximation valid at long distances." **I think from his writing that Weinberg is grumpy**…. He has a demeaning tone in his writing but I also strongly agree with him on several points.

from a post-course interview with a 3rd year sculpture major, female:

I really enjoyed reading Feynman's article. I don't know why, it was my favorite article, because … **to me it really was … a very FREEING notion** of, um – **because I was able to understand what he was talking about – because he obviously writes in a way that is quite understandable** – and, um – so it made me feel proud that I was able to understand what was going on, on a physics level, but I also thought it was very, very interesting.

Reading physics authors instead of a text book does have the effect of making physics more personal:

from a post-course interview, first year physics major :

Jatila: So, do you think that your attitude towards the process of doing physics has changed as a result of doing this course?

SS: I think it HAS, just because of reading the accounts of physicists, like realizing new things and discovering their new ideas. Like, **I think I appreciate physics as more of a creative endeavor now, than I did before**… I guess there's more of a personal aspect to it. Like you kind of have to think outside the box instead of just going along with your math until you arrive at something.

-first year physics major, female

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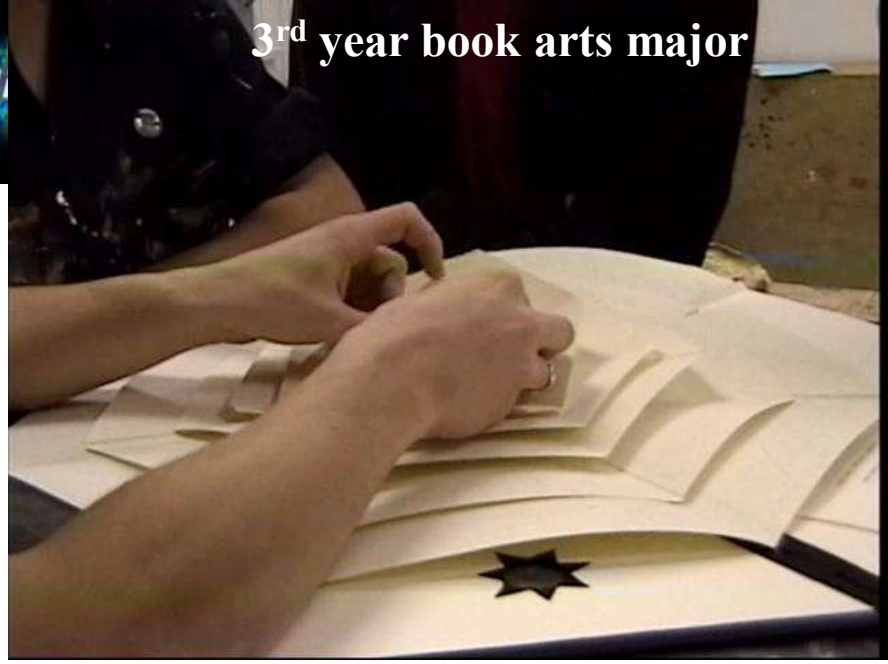
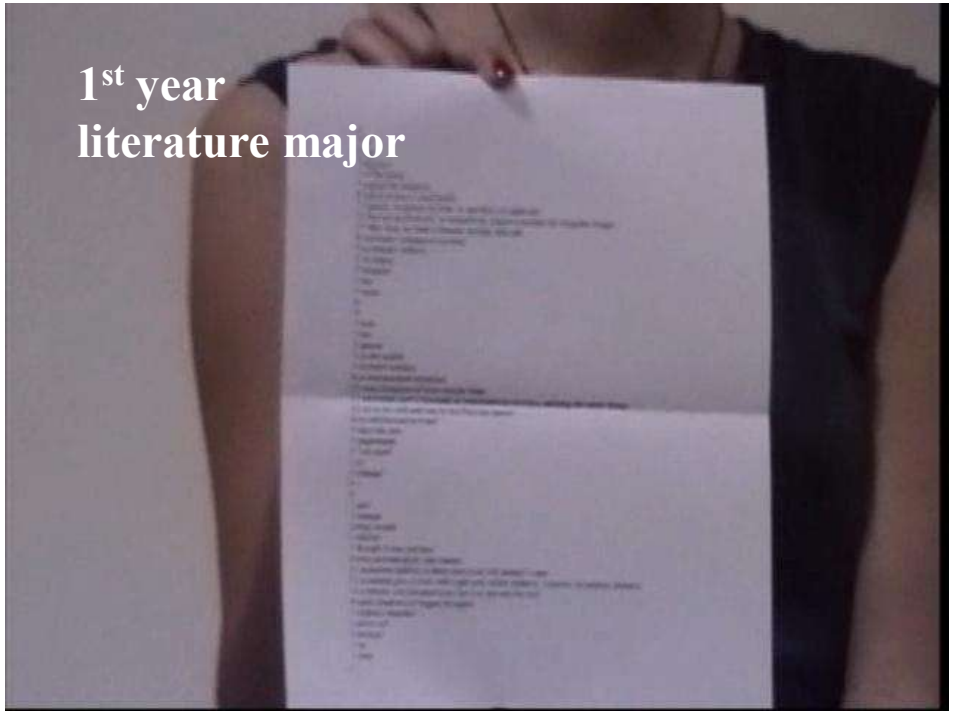
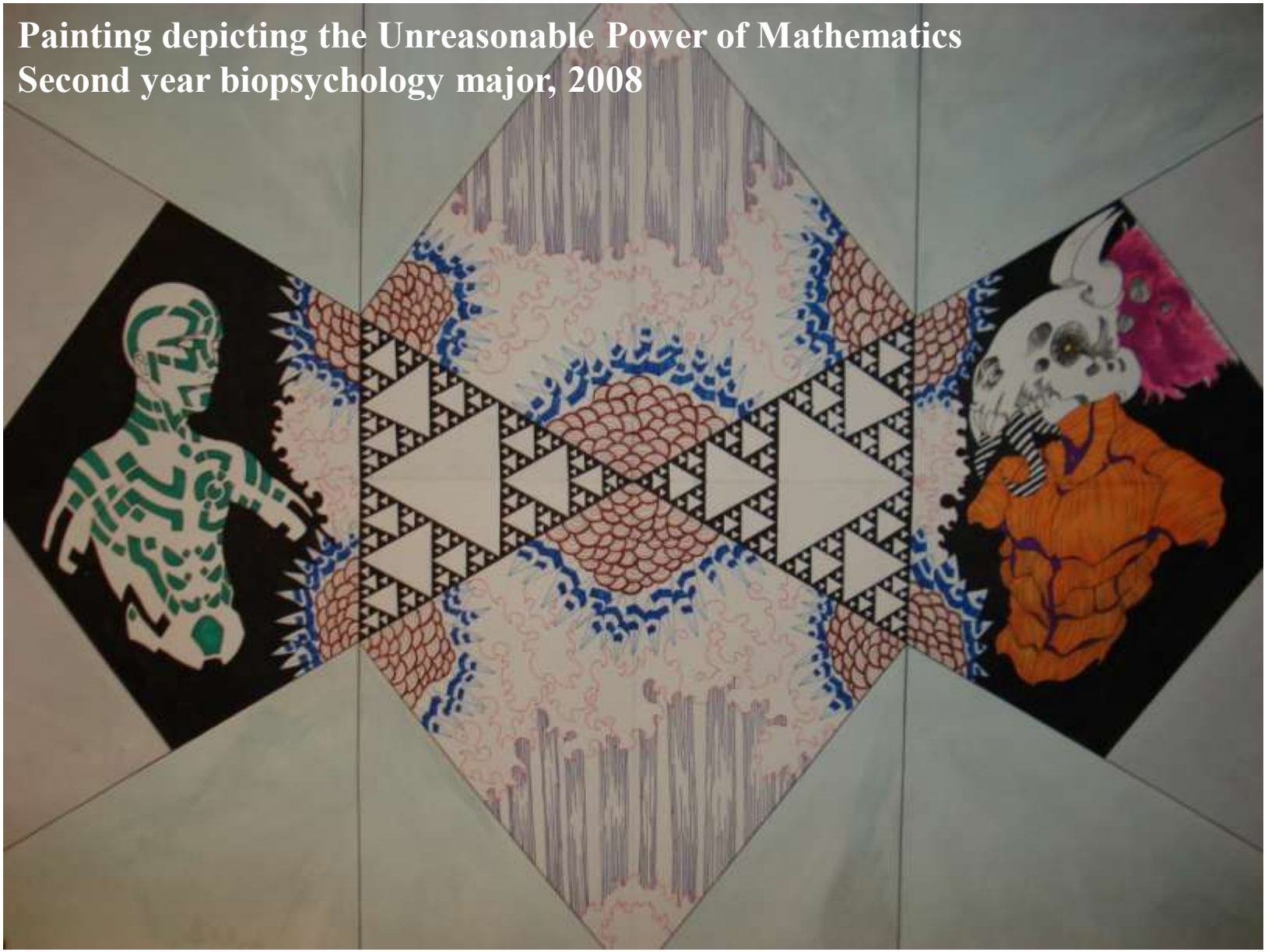
Final projects:
Physics works of Art

Choose your favorite topic from the course, and create a way to represent it in the medium of your choice.





Painting depicting the Unreasonable Power of Mathematics
Second year biopsychology major, 2008



1st year physics major, W2010

4th year painting major, W2011

5. Evaluations and metrics…

Assessments:

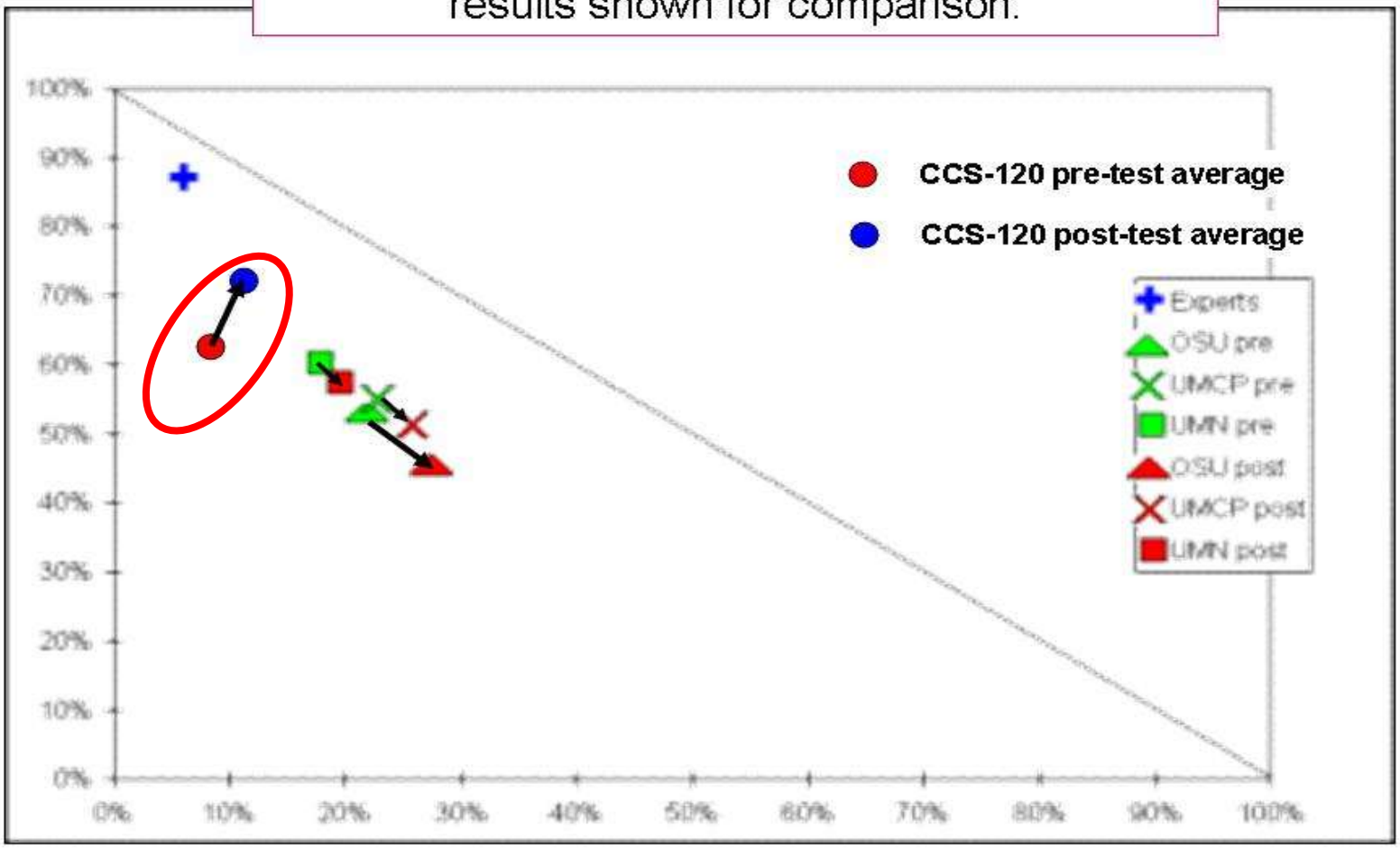
1. Weekly anonymous “exit cards”
2. Final course evaluations
3. In first year: MPEX
4. In first year: Individual and group interviews
5. In first year: Video taping and transcription of students’ conversations

Metrics:

1. Anonymous comments and evaluations: Our course received excellent evaluations from the students each time it has been taught. Rating is consistently in top 1-2% of all courses taught at the university, per quarter and in relation to all courses ever taught. (The same cannot be said of standard intro physics courses…)

2. MPEX: Our students improved in their attitudes towards physics, compared to the published large sample of standard first year classes.

Results of MPEX for RSS survey, with CCS-120 results shown for comparison.



Attitudes toward physics improved during this course, in contrast with national surveys of students in traditional first-year engineering physics courses.

Can this approach really bring more girls into physics?

I think – the beautiful thing about this class was that I felt it was NOT necessarily – this is physics, this is art, keep them apart **– but rather, an all inclusive thing where music and art and physics are OFCOURSE – of course what we talk about and it's – of COURSE it belongs together… and so it's a very different way of seeing, rather than just combining categories.** ***And this is why I was so blown away ultimately, because I realized it was a whole different way to look at the world, at least that's what it was for me.***

~ Third year sculpture major, female, Winter Quarter, 2007

I thought of physics as existing in numbers and equations found by others while I regarded Art to be a result purely from the artist's mind. To tell the truth, I placed Art in a much higher respect than Physics because I never thought of the beautiful process that led to equations and the relation to Nature that Physics possessed. Art was far more involved with Nature and affected it more than any science ever could but throughout the course I found a connection between Physics and Art and found that both shared similar qualities and inspirations.

~ Second year art major, female, Winter Quarter, 2008

Yes - and guys like this approach, too!

What I especially liked about it [the course] was, it got me thinking about a lot of really big, deep questions in physics like, Does the math that we use really have any genuine connection to the physical world? … And, like, all the things that we just take for granted when we're working through problems…
- first year physics major, male, 2007, during end-of-course interview

I think that one of the most important parts about it is that … in your average physics class, or – any physics class for that matter, you're not going t' be studying the other…artistic sides … the symmetries of it all. You're mostly be talking about… the mathematical equations and the logic behind it. But there was a lot in this class that…that we studied … that elucidated a lot of other things that before just seemed as rules to many, so I think that's a good way to approach the subject.

– first year physics major, male 2007, during end-of-course interview

From this year's class:

Thank you so much for teaching this class. I don't think I've ever been quite so stimulated by a class here as much as your class has done for me.

Thank you for one of the craziest (cool) classes I've taken my whole time being here. Not many classes care about what you think... but in your class I felt like my understanding was the whole point. ☺ I really liked

Thank You for opening my mind to Physics concepts I never thought I would Be aBle to otherwise comprehend.

parts to a whole. It was
Thank you so much! My pleasure
to take your class.

This year, for the first time, I had twice as many girls as guys in the class!

6. In Conclusion…

Ten strategies emerged as necessary for a successful aesthetic physics course:

1) Orientation to math as a language of nature;

2) Begin with the contemporary view of symmetry and the paradigm of dynamic spacetime;

3) Read literary works by theoretical physicists instead of a text book;

4) Utilize as wide a variety as possible of assignments and activities, including writing, drawing, composing (or choreographing), in addition to problem solving;

5) Solve math problems *in class, in mixed major groups* in first quarter, so as not to scare away the arts majors;

6) Use interactive methods – Peer Instruction, class discussion, group activities in mixed-major groups;

7) Value equally the scientific and artistic ways of knowing;

8) Have the final goal of the course be a performance-oriented or demonstrable project, rather than a final exam;

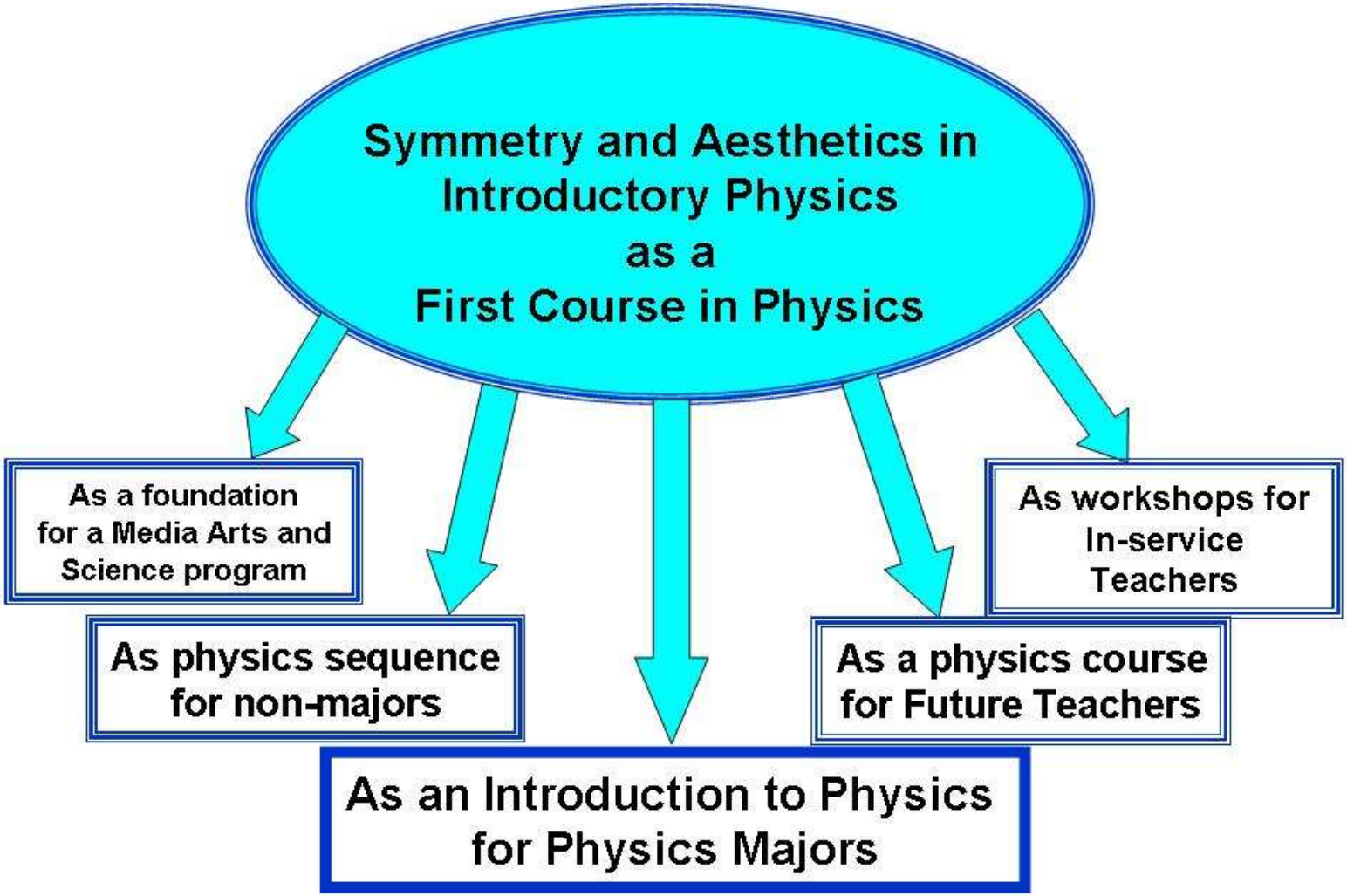
9) Have students write weekly anonymous comments, and make "course corrections" to adjust to their needs whenever possible;

10) Co-teach with other experts, either inviting guest lecturers if possible, or collaborating with colleagues to team-teach.

Guest lecturers: an artist, a cosmologist, a string theorist, a composer

Field trips: KITP art gallery, physics demonstration room, the AlloSphere immersive art-science laboratory

7. Potential Applications in Other Settings



To access materials from this year's course Symmetry and Aesthetics in Contemporary Physics please visit
www.physics.ucsb.edu/~jatila/

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