American Physical Society New England Section Newsletter

Volume 20, No. 2 Fall 2014

Co-editors

- **Edward Deveney**
- **Peter K. LeMaire**

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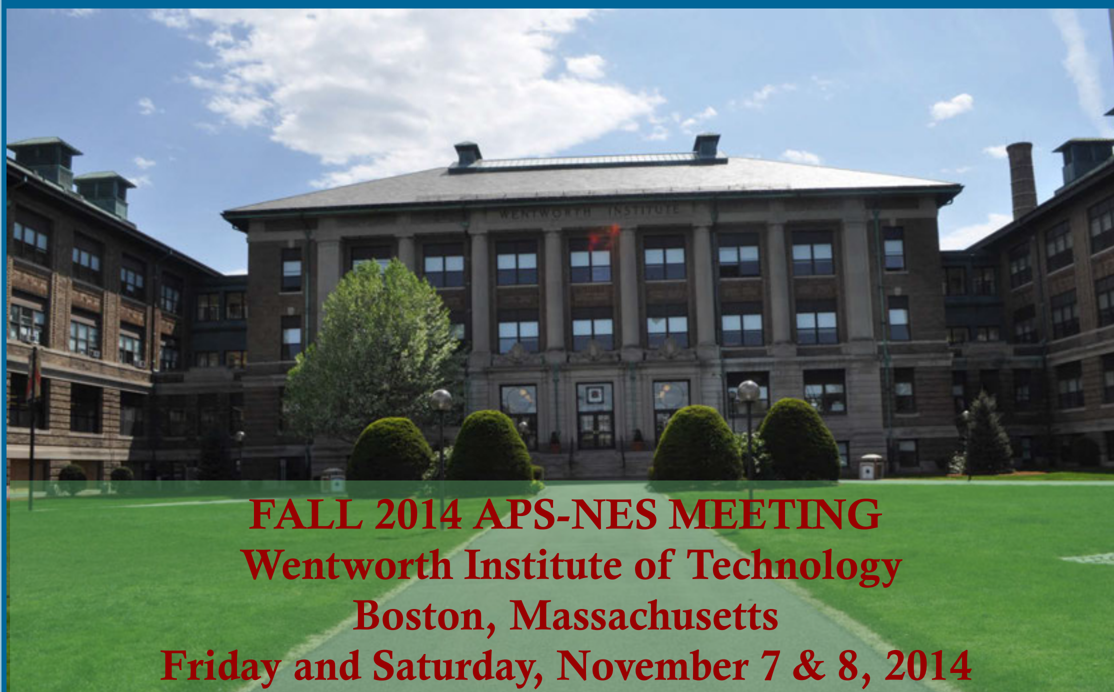


Theme: Physics of the Extremes

Over the past few years physics has been pushing the frontiers of extremes, from the extreme power of the LHC, the extreme searches for dark matter and dark energy, extremely low temperature superconductors and extreme cold atoms. Physicists from large collaborations at the most extreme facilities to the extreme growth in undergraduate research at colleges and universities of all sizes have been testing, expanding and developing the most extreme theories ever dreamed. This meeting will address physics of the extremes and will provide a diverse range of topics featuring invited talks, contributed sessions, a poster session and a session dedicated to undergraduate research. The meeting will begin on Friday November 7th, 2004 with a 12:00pm registration and Meet and Greet. A 2:00pm welcome address will be followed by plenary invited talks, and a conference banquet at 5:30pm. Our featured speaker is **2001 Physics Nobel Laureate Prof. Wolfgang Ketterle** of MIT. Saturday November 8th will include light refreshments beginning at 8:00am leading into parallel seminar sessions until 11:30am. An optional lunch on Saturday will be provided at 12:00pm, followed by a featured session on Undergraduate research in New England!

For complete information including online registration, lodging and meeting schedule, visit the meeting website at http://www.wit.edu/sciences/events/index.html

Meeting Chairs and WIT Contacts: **Professor Naomi Ridge** (ridgen@wit.edu), **Professor James O'Brien** (obrienj10@wit.edu), **Professor Franz Rueckert** (rueckertf@wit.edu)

Recap of the Spring 2014 Meeting of the New England Section of the American Physical Society at Boston College

Prof. Cyril Opeil welcoming attendees to the meeting

Members of the Boston College community and Physics department eagerly welcomed NES APS back to its campus after 42 years and it's last NES meeting back in 1972.

Friday, April 4, 2014|
Opening remarks and introductions made by Boston College Physics Department Chair Professor Michael J. Naughton, and Boston College Physics Professor Cyril Opeil, Chair for the Conference made the compelling case that Energy Matters and that BC is on the forefronts of both the intellectual and material advances bridging energy and matter for brighter sustainable future and world.

Both Professors Naughton and

Prof. Kris Kempa introducing the first invited speaker

Opeil graciously welcomed attendees to some of the treasures that Boston College has to offer which included a tour of the Integrated Sciences Nanofabrication Clean Room Facilities and a, perhaps once in a lifetime, chance to "turn the pages" of writings from 'Three Authors that Changed Our Understanding of the World' housed in the BC Burns Library; Christoph Clavis (1570), Sir Isaac Newton (1687) and Nicolaus Copernicus (1617).

Professor Krzysztof Kempa of Boston College got the APS Invited Plenary Talks off to a start, all taking place in Higgins Hall just up what is called 'the million dollar stairwell' on a cool New England Friday with some attendees taking in a Boston College versus University of North Carolina Baseball game on the way in. "Students commonly refer to the 120 steps, completed in 2001 and named for the science building in the upper left corner, as the "Million Dollar Stairs." The moniker derives from a campus legend that the stairs are internally heated, at a cost of a million dollars, in order to melt snow in the winter. This is, of course, a myth; the Higgins Stairs are dutifully shoveled and salted after every snowfall." (http://at.bc.edu/webcams/higgins/).

Christian Wetzel from Rensselaer Polytechnic Institute began with 'Photons in Energy Efficiency – Solid State Lighting and Beyond', painted the bright future of LED-(semiconductor, junction-based chip) visible lighting in terms of new technological advances, energy efficiency and costs.
Evelyn Wang, Massachusetts Institute of Technology (MIT), spoke on Nano-engineered Surfaces for Thermal Energy Applications, where new research and directions in applying

Christian Wetzel giving his invited talk at the meeting

nano-materials and technologies, nano-engineering, had significant impact on the efficiency of Solar Thermal heat generation and poten-

Evelyn Wang giving her invited talk at the meeting

tial for solar photo-voltaic generation.

Christopher Harrison giving his invited talk at the meeting

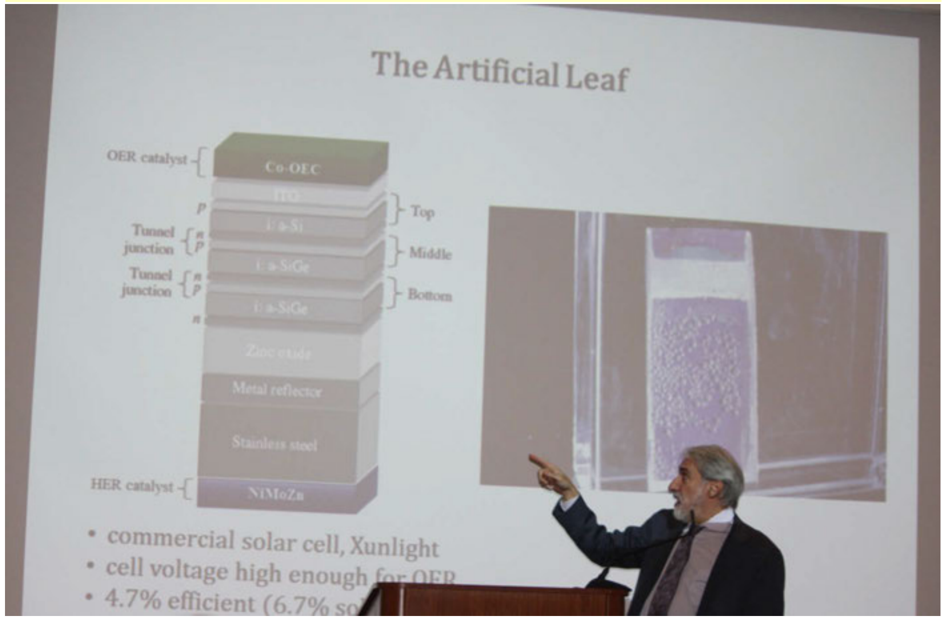
Recap of Spring 2014 Meeting…

Christopher Harrison of the Schlumberger-Doll Research Center spoke on 'Microfluidics and the Oilpatch' taking us all on a ride to an oil field and down a well discovering the application of sensor technologies for increased efficiency and discoveries in oil production.
Following the Plenary talks NES APS members and guests were treated to a wonderful reception and poster session the Heights Room, Corcoran Commons.

The treats continued with a fabulous Banquet dinner and Banquet Talk by **Professor Daniel Nocera** of Harvard University titled 'The Artificial Leaf' that touched on every aspect of the meeting theme, Energy Matters, and delighted the imaginations and practical sides of everyone in the audience.

The Artificial Leaf

By
Daniel Nocera (below)
Harvard University



Scenes from the Banquet talk

Right: ***audience at the banquet talk***

Recap of Spring 2014 Meeting…

After Banquet Chats

Meeting Chair, Prof. Cyril Opeil and Christian Wetzel of Rensselaer chat after the banquet talk.

Banquet Speaker, Professor Daniel Nocera (right) chats with students and other banquet attendees after his talk

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Saturday, April 5th, 2014
Saturday Morning started with light breakfast at 8.30 AM in Higgins Hall followed by Plenary talks and Contributed talks that showcased how Energy Matters at Boston College:

Professor Kris Kempa: *Towards Ultra-High Efficiency Solar Cells*.

Professor Kenneth Burch: *New Properties by NOT Treating Materials Like Legos.*

Contributed talks by Boston College Undergraduates and Graduate Students.

Joseph Liguori, undergraduate student: *A New Source of White Light: Oxide Nano-Powders Illuminated by a Laser Diode*

Mani Pokharel, graduate student: *Thermoelectricity of $CeAl_3$*

Mengliang Yao, graduate student: *The Thermoelectric Transport Properties of α-phase Cu_2Se Compounds with Adjustable Charge-density Wave.*

At just about noon the meeting was called to end and a fine NES APS meeting was adjourned. Traditional Saturday afternoon lunches boxes were served and eagerly consumed while the NES APS executive had theirs at the post-meeting executive council meeting. Congratulations were much deserved for all organizers, presenters, attendees and guests – and for all of those it was wonderfully clear, Energy Matters.

Author: Ed Deveney,
Department of Physics
Bridgewater State University

(Meeting pictures courtesy of Peter LeMaire, Central Connecticut State University)

Focus on Wentworth Institute of Technology

WIT Quad

Wentworth Institute of Technology's commitment to career success is truly EPIC—an Externally-collaborative, Project-based, Interdisciplinary Curricula for learning. Wentworth is an ideal learning environment situated in the heart of Boston, affording access to a vast array of external partnerships, and allowing professors to make the entire city their classroom. Industry leaders visit the Institute to work directly with classes, and all students must take part in a robust co-op program spanning two full semesters. Wentworth is also home to the Accelerate Innovation + Entrepreneurship Center, which provides students with the chance to test products and ideas in a collaborative environment and make their entrepreneurial dreams a reality. Additionally, Wentworth Institute played host to the 2013 and 2014 Polytechnic Summits, allowing visitors from across the country to discuss and showcase new ideas and pedagogical advancements in the STEM fields. This learning approach is particularly evident in the Institute's physics program. The physics faculty is housed in the WIT department of Sciences, shared with biology and chemistry. The diverse sciences faculty have the privilege of working with students across the entire spectrum of the Institute. Wentworth students can earn a minor in physics with undergraduate research and innovation as the cornerstone of the program. The department's commitment to EPIC learning is highlighted in some of its recent endeavors. These include an EPIC collaboration to create a cutting edge, game-based learning tool called

Sector Vector

Provost playing Sector Vector with students

Sector Vector, a project based revamping of the conceptual physics course as well as a self sustaining biodiesel synthesis project.

The aforementioned Sector Vector board game was developed through the interdisciplinary work of physics professor James O'Brien, chemistry professor Greg Sirokman, industrial design (ID) professor Derek Cascio, and their Wentworth students. The game uses the backdrop of an intergalactic space battle to illustrate vector systems. While the game serves as a learning tool for physics courses, the

Focus on Wentworth Institute of Technology

design of the game itself was carried out through the ID department. Although collaboration is at the heart of the design curriculum, typically the students focus on external collaborations outside of the college, whereas this project brought students from different disciplines together. "I believe this is a testament to how exciting cross disciplinary projects can be and how presenting a unique and innovative program with lots of potential can be highly motivating" says Derek Cascio. The close workings of these two departments achieved a dual learning goal. Physics students who participated got to learn about design and implementation of ideas, where as design students had a chance to learn some intensive physics and mathematical calculations that needed to be preserved in the game design. "My favorite outcome of this project was that we got to create a product from the ground up, that was designed by WIT students that will be used in the teaching of future WIT students" says professor O'Brien. Sector Vector has been well received in the physics community with a peer-reviewed publication on the project as well as a blog post on physics today (http://physicsbuzz.physicscentral.com/2014/04/flex-your-vector-skills-in-new-game.html).

With a focus on project-based learning in mind, Professor Franz Rueckert recently redesigned the Conceptual Physics classes at WIT. Interactive learning and group projects are emphasized over problem solving and calculations, an approach more in line with the learning experiences of the students involved. This has led to the development of several new labs, and lecture sessions now often feature in-class activities and hands-on demonstrations. Rather than

Biodiesel reactor

solving problems from a text, homework now takes the form of case studies. Students are asked to read an article or watch a video describing various situations. These include the launch of the space shuttle or famous structural failures. The assignments foreshadow upcoming material and serve a launching point for class discussion of the week's topics. As a centerpiece of the course, midterms and finals are replaced with a group project: the construction of a Rube Goldberg chain-reaction machine to raise a WIT flag (see RGM article next). Students were asked to showcase a particular Physics topic in each section of the machine. In presenting their machines to the class, the students demonstrated their new understanding of Physics and their ability to use that knowledge to evaluate form and function; a key goal of the course.

The Department of Sciences at WIT is interdisciplinary in nature, and undergraduate research in chemistry and biology is also conducted. One particular project that has had a long lifespan is the biodiesel project. This project began in 2010, when students from the Environmental Science program began testing conditions for the processing of vegetable oil into high quality biodiesel. Their goal was to be able to convert the used vegetable oil from the campus cafeteria into biodiesel to be used elsewhere on campus. These students then went on to design and build a ten gallon biodiesel processor as their senior project. They successfully completed the processor, and several batches of high quality biodiesel were produced. The success of the project led to the inclusion of the Blaisdell Biodiesel Lab in the construction of the new Center for Sciences and Biomedical Engineering. The reactor is

Student making biodiesel

now awaiting reassembly by a new team of students, and once it resumes operations, should be able to supply the Wentworth Facilities Department with 10 gallons of biodiesel per week. The department of sciences has many other exciting projects in the works such as 3-D printing of muscles, development of teaching tools in the sciences for blind students, and synthesis of proteins. Through all of these avenues, the department of sciences helps forward WIT's vision of EPIC learning.

Author: James G. O' Brien, Ph.D.
With thanks to Greg Abazurious
Department of Sciences and Applied Mathematics
Wentworth Institute of Technology

Focus on Wentworth Institute of Technology

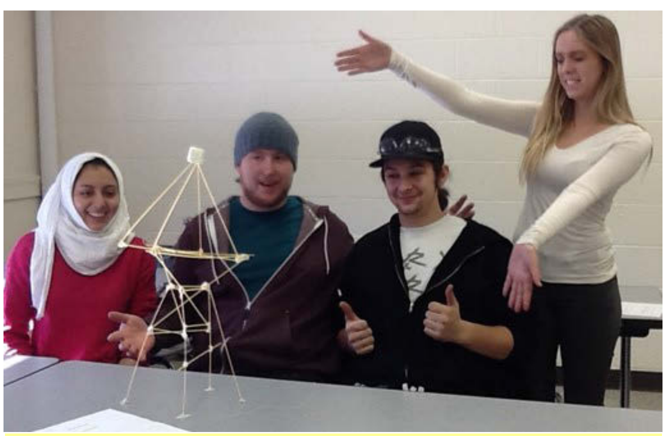
Rube Goldberg Machines: Using complexity to simplify physics

Courses in Conceptual Physics are common at many institutions, focusing on the scientific procedures and reasoning of physics with less emphasis on equations and formulae. While often an elective, at WIT Conceptual Physics is a required class for several majors. By far the largest segment of those enrolled are students from WIT's well known Interior and Industrial Design programs. The learning environment to which these students are accustomed differs widely from the traditional setting. A design student is charged with the realization of an idea; as such much of their time is spent in studio or various shops prototyping and refining long term projects. Previous iterations of the Conceptual course found difficulty fully engaging these students and relating course topics to their field of interest.

Wentworth continues to advocate the inclusion of EPIC learning opportunities at every level of the curriculum. In keeping with this theme, an effort has been made to more effectively align the class goals with those of the design program by taking a project-based approach to the discussion of a variety of physics topics. The goal of this version of Conceptual Physics is to improve the ability of students to evaluate form and function through an understanding of physics principles.

Class topics are reinforced in longer laboratory challenges like the pasta bridge

The course is divided into weekly modules covering a selection of topics important in the design process. These include areas like motion, forces, stress and strain, structure, vibration, and energy. Each aspect of the class has been focused on practical examples. Case-studies are used as homework assignments before each module, generating in-class discussions as the introduction to new topics. Lectures are often broken into group analysis and deliberations as new ideas are covered, and include demonstrations and hands-on investigations. Laboratory sections allow a longer exploration of key concepts, and are structured as challenges which encourage students to use their creativity as a tool for learning.



Students completing the Marshmallow Challenge as an in-class demonstration of structure and equilibrium

One challenge in instructing this type of course is evaluation. It can be surprisingly difficult to gauge student understanding without the mathematic formalism of a typical course. Another question is how one tests comprehension rather than memorization. Within the design program, such points are moot as students are evaluated on the presentation and success of their projects rather than traditional testing. Thus, a project-based approach is also taken regarding examinations. While short quizzes are offered throughout the course, midterms and finals are replaced with the semester long construction of a Rube Goldberg chain-reaction machine (RGM).

Goldberg is most famous for his cartoons showing devices which preform relatively simple tasks in needlessly complex and elaborate ways. While often used for humor, these devices are also an analog for the understanding of physics; a set of basic concepts which combine in intricate ways to produce the world around us. The successful conceptual student learns to appreciate that the seemingly simple is in fact the

Focus on Wentworth Institute of Technology

Students working on, and testing their RGMs

end result of a long chain of physical interactions.

For the RGM project, students are tasked with creating a multi-stage device to eventually raise a WIT flag. Each section of the machine is used as a showcase of a particular topic. Individually, students must also submit a written schematic of their machine explaining its operation and the physics involved. Students are graded on the written portion, the success of the machine, and their in-class presentation. The ability of the students to explain their machine is a key indicator of their comprehension. A portion of the grade is attributed to the "wow factor" of their RGM. What constitutes this factor is left purposefully vague. In this way, the creativity and resourcefulness of this population of students is again used to reinforce the learning environment.

Student engagement with the Conceptual Physics has been noticeably improved, and it is hoped retention of class topics will be likewise enhanced. The restructuring of this class has benefitted from the resources available to the WIT design program, including access to materials, knowledge and availability of manufacturing tools and supplies, and studio space for construction. In making the course more consistent with the design process, students are able to apply their unique skill set to physics education. In fact, the practice of prototype, enhancement, and refinement cycles is not so different from the practice of scientific research, which also requires a good deal of creativity and originality. This approach is central to a number of disciples. As WIT continues to develop new EPIC learning opportunities, efforts are underway to expand Conceptual Physics to a wider array of majors. Through consideration of the similarities and differences of diverse learning styles, and some clever RGMs, the complexity of physics can be understood and enjoyed rather simply.

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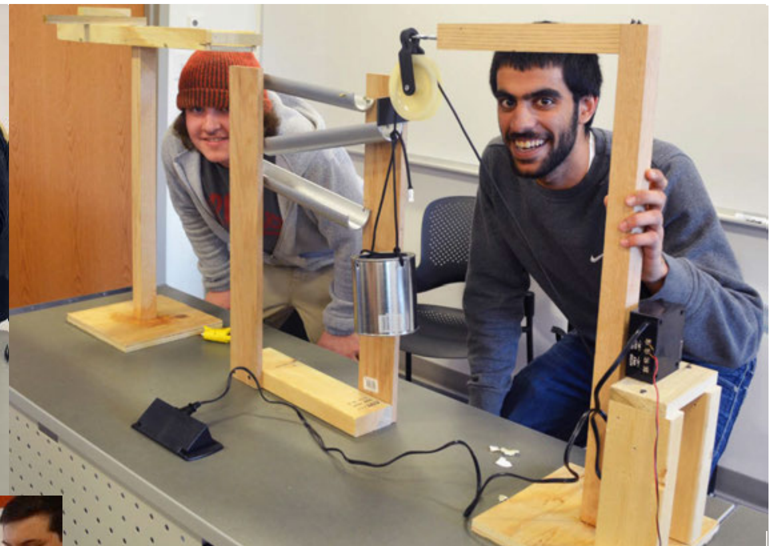
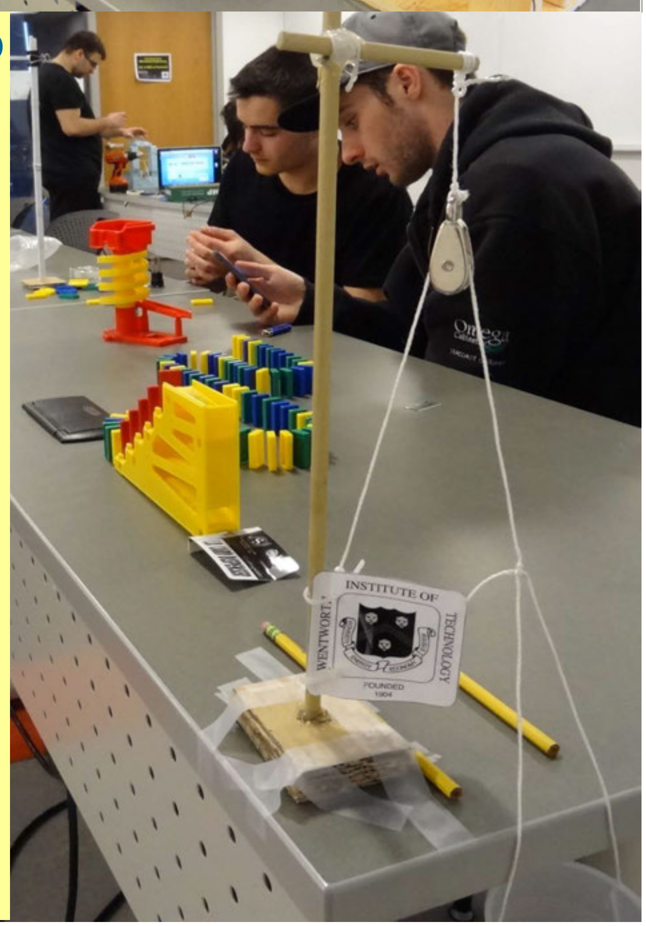
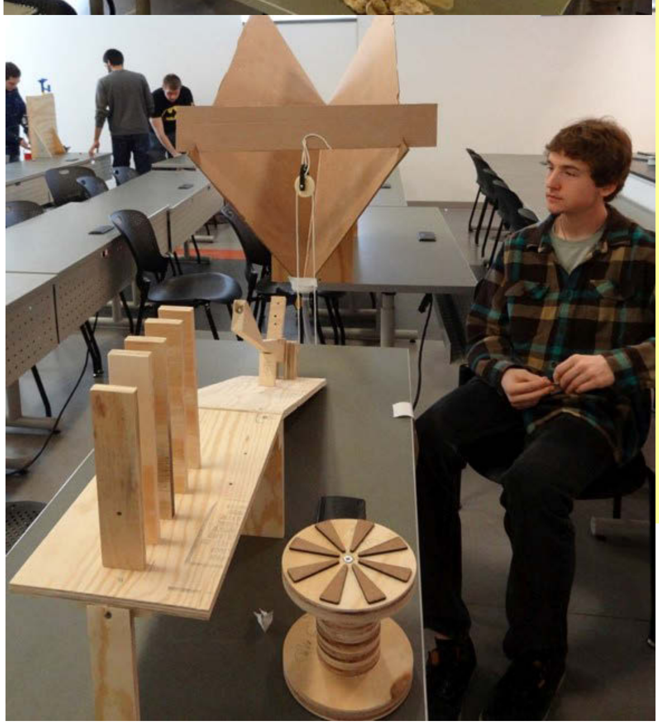


Rube Goldberg



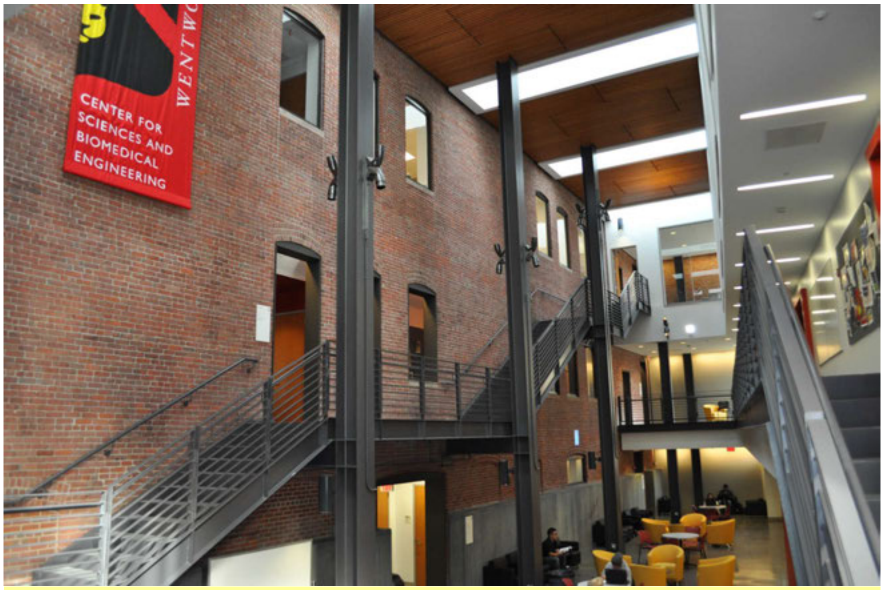


Author: Franz Rueckert, Ph.D.
Department of Sciences, Physics
Wentworth Institute of Technology

Focus on Wentworth Institute of Technology

Sciences at WIT

Over the last five years, the WIT department of sciences has undergone an impressive transformation. In this short time, ten new faculty members have been hired in the fields of biology, chemistry, and physics. Furthermore, the department is now housed in the brand new Center for Sciences and Biomedical Engineering. The former Ira Allen building, circa 1901, was completely transformed to meet modern needs in science education. Renovations include 11 new dynamic teaching laboratories and a recitation room, along with faculty offices, open collaboration spaces, and a 2,000 sq. ft. gathering forum for students. Additionally, the department now offers minors in physics, chemistry, biology, and bio-informatics that align the curriculum with the institution's shift toward EPIC learning. At the heart of each is a robust undergraduate research program lead by faculty members across these disciplines.



Interior of The Center for Sciences & Engineering

The addition of the Physics minor necessitated the creation of several new classes. Upper level courses in Astronomy, Astrophysics, Computational Physics, Acoustics, and Quantum Theory have since been added, with an overwhelmingly positive response from students. Under the guidance of professor James O'Brien, a number of these students have gone on to participate in EPIC physics research. Highlights of their work include five small grants and both poster and oral presentations at the national APS April meetings of 2013 and 2014.

In the research component of the physics minor, students are exposed to all facets of a scientific investigation. Weeks before the course begins, students meet regularly with the chosen faculty advisor to discuss their interests and goals. By the start of class, topics are chosen and research is conducted independently, with weekly meetings as guidance. The students are responsible for writing a full proposal and budget for the project. At midterms, project proposals and budgets are updated and an oral report on progress is given. The course concludes by mirroring the dissemination process, requiring a formal scientific paper in a typesetting language (Latex), a professional poster, and a fifteen-minute oral presentation.

Senior Computer Science student Robert Moss carried out one of the most successful EPIC projects. Inspired by his Modern Physics course, Robert expressed interest in computational modeling of the galactic systems central to Dr. O'Brien's research. Robert drew from his extensive CS experience to first make a stand-alone modeler for galactic rotation curves using general relativity. Realizing the utility of his modeler as an analytic tool, he then reached out to various authors in the field of gravitation and used his work to simultaneously fit and compare rotation curves for

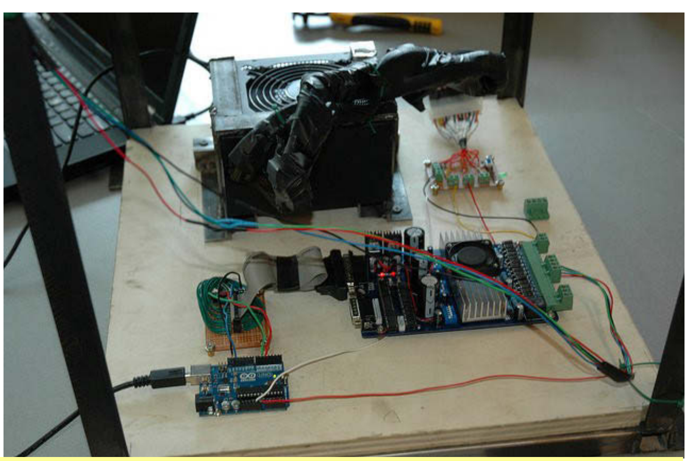
New Bio Labs

Focus on Wentworth Institute of Technology

New Chem. Labs

multiple alternative gravitational models. Although more than enough for an undergraduate project, Robert continued his efforts and created a central database for the modeler to draw from. The database is now a public entity that astronomers can update as new data becomes available, making his work a lasting contribution to the field. He presented his work at the undergraduate symposium at APS April 2014 in Savannah, and recently submitted a paper to the Journal of Undergraduate Research in Physics (*JURP*). Robert graduated in August with high honors and has accepted a position at MIT Lincoln Laboratories.

While some of the undergraduate research projects are tailored to specific students, long-term projects also exist which pass from one group of students to the next. For example, in the fall of 2013, ten WIT students began the initial work on the Wentworth Radio Array Telescope (WRAT). Students were divided into two interdisciplinary teams and tasked to construct receivers and data interface modules to convert rooftop satellite dishes into radio telescopes. Both teams were able to design simple receivers to detect the 21cm HI line, small changes in the magnetic field of Jupiter due to its moon Io (similar to radio JOVE applications), and a means of detecting meteors entering the atmosphere. The students were given the chance to design hardware, software, and collect and analyze date. The hands-on approach led to an in-depth understanding of all aspects of amateur radio astronomy. The project was presented at the 2013 Polytechnic Summit and concluded with a field trip to New Hampshire to perform continuum measurements on the transiting of the spiral arms of the Milky Way galaxy.



Radio Telescope motor guts

As WRAT is a long-term project, two senior students began the next phase of the project in the spring of 2014. Ryan Wilson and Ed Winters, seniors in electrical and mechanical engineering, used their respective expertise to design and implement further functionality to the telescopes, adding a rotation platform and 180 tilting arm for full control of the dish. To complete and better automate the project, a cell phone application was created to drive the telescope and allow for remote observation. This phase of the project took the WRAT outside the realm of typical amateur astronomy and opens the door for more intensive observational applications in the near future. For the current phase of the project, teams of Networking and Computer Engineering students will take the now moveable and trackable dishes and allow them to communicate together as a true small array. "The benefit of a mixture of long-term and stand-alone projects is flexibility. Students with a particular interest can explore new territory, while existing projects generate excitement and allow for interdisciplinary partnerships" says Professor O'Brien.

"Undergraduate research in physics is the perfect vehicle to implement EPIC learning in the sciences," says Robert Moss. Students at WIT are already well versed in the EPIC learning model and the undergraduate research component of the physics curriculum gives students a realistic exposure to the world of science. Taken together, they help foster the independence and ingenuity required in their future engineering careers.

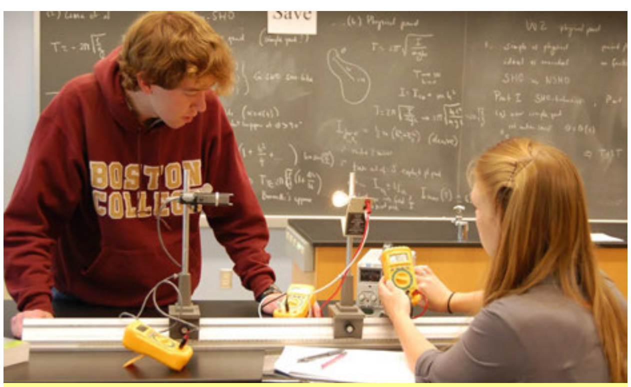
Author: James G. O' Brien, Ph.D.
Department of Sciences and Applied Mathematics
Wentworth Institute of Technology

Boston College Lab in the Spot Light: A little more is a little different

When I joined the Department of Physics at Boston College late last millennium, and started teaching an unlikely pair of courses (introductory physics and the graduate level mathematical physics), I could hardly anticipate that one day I would be responsible for the undergraduate laboratories. I had been, after all, trained in mathematics and had interest in theory of elasticity and analytical fluid dynamics. Our teaching laboratories were at the time directed by a much beloved colleague, officially already retired, who designed some beautiful experiments. The apparatus was to a large degree home-made with the sensors operated by LabView. By the time I arrived, however, much of the equipment was outdated and in poor condition, with parts that could no longer be replaced, and a number of experiments morphed into computer simulations (still quite crude then). In short, the labs needed to be modernized.

An opportunity to do just that arrived when it was time to renovate and expand our building, shared with Biology, which was to double in size in order to accommodate expanding research laboratories. The renovation budget included an additional fund set aside to refurbish teaching labs (in physics and biology) and for modern equipment to be installed in our beautiful, new space. Since my senior colleague had by then fully withdrawn from teaching, and I was around, I was asked to lead this transformation and also help create two newly conceived sophomore-level laboratories.

Much as I was eager to take on this challenge, I had, unlike my predecessor, little experience in designing electronic components, building sensors, or machining parts, though I had done my share of tinkering with circuits, mechanical contraptions, etc. Thus instead of building apparatus from the ground up, I decided to focus on creating engaging, instructive (and to the degree possible open-ended) experiments, and use the best equipment available from commercial suppliers.



Students working with "Stefan-Boltzmann Lamp" and sensor

My first goal was to return to the "old fashioned" notion that experiments should be based on real apparatus, and that computer simulations were better left for students to explore on their own. We use computers to automate data collection and reduce the tedium of repeated steps in their analysis, but still have students do some measurement by hand or by reading analogue or digital meters. And while most of our experimental setups are ready made (by Pasco, TeachSpin, Sargent-Welch, and Elwe, plus some custom made circuit boards, power supplies, etc.) we have strived to do the most with the equipment we have, and to tease more out of it than the makers may have envisioned. Two examples follow, one from the introductory and one from the Sophomore laboratory.

The first example is a "standard fare" investigation of colliding particles constrained to move in one dimension. Pasco tracks and carts, with their Velcro (for inelastic collisions) or magnetic (for elastic collisions) bumpers, and the ultrasonic motion sensors, are quite suitable for this purpose. The trouble is that one can measure linear momentum and kinetic energy with sufficient precision to see that neither is conserved in any of the collisions! This is of course due to persistent friction—mostly rolling friction in the carts' wheels—which simply cannot be ignored.

The remedy is to look closely at what happens not just before and after, but also *during* collisions. Figure 1 is a plot of the total kinetic energy K of two identical carts, of which one was initially stationary, before, during, and after a nearly elastic collision. As expected, K decreases linearly overall. But you can also see what happens during the collision: kinetic energy decreases, reaches a minimum, and then increases back up. Where did the energy go for about 0.5 seconds? Well, it was stored in the "spring" between the carts, i.e. in the magnetic field. The dip in figure 1 is parabolic, indicating that the force between the carts was nearly constant (which can be seen more directly in plots of their linear momenta). But why should this be the case given the force between two magnetic dipoles varies rapidly with the distance d between them (as d^{-4})? And what sets the value of the lowest total kinetic energy in such a collision?

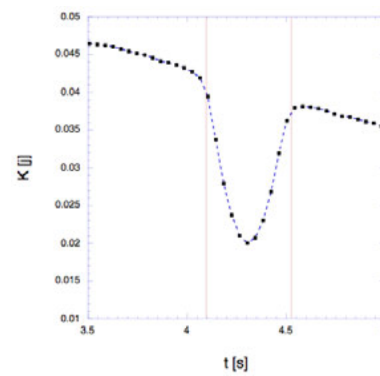


Fig. 1 : Total Kinetic Energy

The second example is the classic black body radiation experiment, which we include in the labs accompanying our sophomore-level modern physics course. The main part of the apparatus is a high temperature source of radiation and a radiation sensor (Pasco's "Stefan-Boltzmann Lamp" and sensor, see the accompanying photo). The sensor's output is in mV, and the suggested experiments are to test the Stefan-Boltzmann Law for radiation intensity, $I = \sigma T^4$, but without trying to measure σ. This constant, however, is of great interest as it connects thermal physics (Boltzmann constant k), quantum mechanics (Planck's constant h), and electrodynamics (speed of light c), in a beautiful ex-

Boston College Lab in the Spot Light: A little more is a little different

pression which involves all integer power exponents between 1 and 5,

$$\sigma = \frac{2}{15}\frac{\pi^5 k^4}{h^3 c^2}.$$

Moreover, one of the guiding principles of our sophomore laboratory is that students obtain their own values of several fundamental physical constants using modern apparatus based on the original designs: the speed of light *c* (rotating mirror set-up, Fizeau and Foucault 1850); Planck's constant *h* (photoelectric effect first identified by Hertz in 1887); and the charge of the electron *e* (Millikan's oil drop experiment, 1909-1914). By measuring σ, the students could then also claim their own value of the Boltzmann constant *k*.

This goal is easily attainable with the Pasco apparatus provided the sensor is calibrated to convert its output into watts, which is done most conveniently by measuring the product , κ*A* where κ is the conversion factor (in V/W) and *A* the area of the emitter, tungsten coil inside the lamp, hard to obtain separately

$(\text{we find } \kappa A = (0.34 \pm 0.02) \times 10^{-3}\ Vm^2/W)$.

With this calibration at hand, it is now a straight forward matter to obtain the experimental value of σ from the plots of *I* versus T^4 at various distances between the emitter and the sensor.

However—and this is our second modification—a much nicer and more insightful way of handling the data taken at various distances is to combine them all in a single plot of intensity *I* as a function of sT^4, where $s = s(d)$ is the fraction of the emitted radiation which reaches the sensor at distance *d* from the emitter

$(s \approx r_o^2/4d^2,\ r_0$ is the radius of the sensor's circular aperture). This plot is given in figure 2. There is a lot of physics here, and the slope of the linear fit normalized by the emissivity of Tungsten (about 0.4 with 10% accuracy in the relevant temperature range, $400\text{K} < T < 3000\text{K}$) gives σ to within 4% of the accepted value. Now, is the *I*-axis intercept truly nonzero and negative? And, if so, what does it depend on?

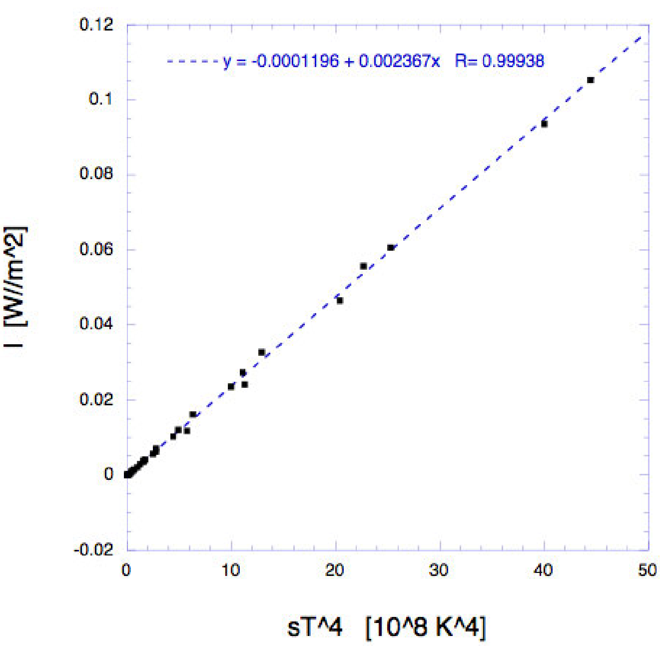


Fig. 2 : Intensity of Radiation

Looking a bit more closely at familiar experiments can indeed lead students (and instructors) to some new quantitative observations and qualitative questions. Or, to paraphrase the well-known adage by Phillip W. Anderson[1]: a little more is a little different!

Acknowledgement: The author owes a debt of gratitude to Yun Peng-Szatanek, who wrote the code used for the plot in figure 1, took all the data shown, and took the photograph. I am also thankful to physics students Laura Simko and Peter Czajka, who agreed to look at our black body radiation set-up one more time.

[1]P.W. Anderson, *More is Different*, Science **177** , 1972, p 393-396.

Author:
Andrzej Herczyński
Department of Physics, Boston College

Gerald S. Guralnik (1936—2014)

Gerald S. Guralnik, Chancellor's Professor of Theoretical Physics at Brown U died on 26 April 2014 shortly after he collapsed while giving a physics lecture. He was first author of the most complete paper predicting the existence of what is now called the Higg's Boson, the "God Particle."

His colleague and co-author, Carl R. "Dick" Hagen, wrote a tribute to Guralnik's pioneering research that was published in the August issue of "Physics Today." http://scitation.aip.org/content/aip/magazine/physicstoday/article/67/8/10.1063/PT.3.2488

Hagen did not call the particle they predicted back in 1964 the "Higgs boson," but the SBS (Spontaneously Broken Symmetry) boson – the so-called God Particle. Gerald Guralnik, shortly before he died, e-mailed me that it was first called the GHK boson. Guralnik, Hagen, and Kibble wrote the highly cited paper, which was published a few months after those of Englert and of Higgs, who shared the Nobel Prize. The GHK paper is nevertheless regarded as the most complete paper.

My PowerPoint presentation using the vugraphs that Gerald kindly sent me before he passed away is available at http://www.slideshare.net/paulhcarr/aspec-higgs-predictiondicovery It includes the *Science News* article, "Nobel's Sharp Cuts: How Gerald Guralnik just missed the physics prize."

Submitted by
Paul H. Carr
Air Force Research Laboratory (Emeritus)

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Ed Deveney (edeveney@bridgew.edu)
Peter LeMaire (lemaire@ccsu.edu)

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