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Turning Teaching Upside Down

Studio Physics Makes Learning a Collaborative, Hands-On Experience



Students in Studio Physics work in teams to take measurements, develop animations, and report their results.

they simply sit in a lecture and ponder the questions. They work in teams to take measurements; then go to their laptops to produce simulations and three-dimensional animations to see if those measurements were correct.

This is how Studio Physics works. Gone is the familiar routine of simply going to lecture, reading the text, finishing the homework, and taking exams. Hands-on activities replace passive learning. Student success depends on a balance of independent work outside the classroom and close collaboration in the laboratory. Alongside the department's other class offerings, Studio Physics gives

Say a coffee filter drops from a tall building and reaches the ground in 50 seconds. What was the upward force of the air resistance while the filter is falling at terminal speed? What about four coffee filters instead of one? For students in Dr. Stuart Elston's Studio Physics class, this is not an abstract exercise where

students yet another choice in finding a physics course that matches whatever way they learn best.

What, Exactly, is Studio Physics?

Studio Physics dates to the early 1990s. The fundamentals are a closer integration of lecture and laboratory, less time devoted to lecture and more to faculty-student interaction, and collaborative group work in a technology-enhanced learning environment. Students spend the majority of their class time teaching each other through hands-on activities. This is part of what developers call a "flipped" or "upside-down" pedagogy, where students learn the basic material on their own before they come to class.

Elston first learned about Studio Physics about eight years ago. To see firsthand how the program works, he and Dr. Jim Parks, Director of UT's Undergraduate Physics Labs, visited North Carolina State University, which uses a method called SCALE-UP: Student-Centered Active Learning Environment with Upside-down Pedagogies. After substantial planning and design work, UT began its own program, complete with the transformation of Nielsen Room 207 into a true Studio Physics classroom. There are round tables that are seven feet in diameter, each seating nine students (three groups of three) to encourage collaboration. There are also laptops, as well as a range of experimental equipment.

"A lot of work went into that," Parks explained. "We almost doubled our introductory lab equipment to be able to do this. Now, we couldn't do without that room and

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Closing the Gap

by Hanno Weitering

I am sure many of you will miss the familiar photo of the friendly bearded man on the cover page of CrossSections. After 12 years of distinguished service as Head of the Department, Professor Soren Sorensen decided it was time to step down. He certainly has left a big footprint on the department, which can be somewhat intimidating for a new head. I sometimes can't help thinking that the Master might be secretly watching over my shoulder to make sure I don't mess things up. I should know better of course. Soren has much more interesting things on his mind, such as renewing his involvement with potentially ground-breaking experiments on the Quark Gluon Plasma at Brookhaven and at CERN. I surely hope his students will allow him to turn the knobs in the lab and wish him all the best in becoming a "hands on" experimental physicist once again. Thank you, Soren!

Since I took over the helm in August, my life veered into the fast lane. The fall semester is loaded with administrative deadlines, proposal deadlines, budget proposals, and all kinds of meetings. It is very difficult to maintain control of your own calendar and one easily feels overwhelmed. However, during those moments I have come to appreciate how smoothly and professionally our department is operating. This makes the life of a department head a lot easier. It is not only a great compliment to my predecessor, but also to the associate Heads, Dr. Jim Parks and Professor Marianne Breinig, and the entire departmental staff. Another aspect that really makes me appreciate my new job is the many personal interactions. I now know my colleagues better than before and I have met so many new people. It is great to learn about the accomplishments of my fellow faculty members in research areas that are different from mine. It is a pleasure to get to know people from the other departments and from the College. It is a humbling experience to find out that other departments may be doing just as well. Physicists certainly can learn a lot from them.

Department Demographics

One of the reasons why I became interested in the Head position is that the department is going to change in the near future. The demographics of our department indicate that the department will look very different in 2020. As more and more of our esteemed senior colleagues start enjoying retirement, younger faculty will become the new

face of the department. I remember the time I was hired as an assistant professor in 1993. When I came up for tenure 5 years later, I still was the youngest faculty member in the department. Very few young faculty were hired at the time. Even though we have hired quite a few assistant professors since then, the age pyramid of the department is still inverted.

I am very optimistic that we will be able to hire many young assistant professors within the next decade. Of course, the department head is not the one to decide who will be hired next, but he is privileged to be in the midst of these exciting developments.

In 2012, the steady decline of the faculty size finally came to a halt. In fact, we have started growing again. This fall we have welcomed two young faculty members, professors Christine Nattrass and Haidong Zhou, while we have lost no one due to retirement or other departures. Christine specializes in experimental relativistic heavy ion physics and is heavily involved with the ALICE experiment at CERN and the PHENIX experiment at RHIC. Haidong is an expert on synthesis and properties of advanced highly-correlated electrons materials that are currently at the forefront of condensed matter research. He was a student of the prominent solid-state physicist John B. Goodenough at the University of Texas, Austin, and spent several years as a postdoctoral fellow and staff scientist at the national magnet lab. Last but not least, Tony Mezzacappa from ORNL is joining the physics department as a joint faculty professor. Many of us know Tony pretty well personally. Others may know Tony from his pioneering work on the mechanism of the core collapse in supernovae. In his new job as Director of the UT/ORNL Joint Institute for Computational Sciences (JICS), Tony will lead an ambitious effort to position JICS as one of the very best computational science research institutes in the US. His most immediate task, however, will be to lead UT in its effort to compete for the renewal of the KRAKEN, which is



Dr. Hanno Weitering
Professor and Head

As the Chancellor has eloquently said many times, “the journey we take is as important as achieving the goal.” The strong support from faculty, staff, and university administration indeed makes me feel quite optimistic that as a department, we stand to reap great benefits from the top 25 initiative.

one of the most powerful supercomputers operated by an academic institution. We wish all of our new colleagues the very best. Finally, as the icing on the cake, there are now two more faculty searches underway.

The Top 25 Aspiration

A growing faculty size is an important component of UT’s top 25 aspiration. Among the top 25 public physics programs in the U.S. (according to U.S. News & World Report), there are only 3 physics departments with fewer than 44 faculty members, while the average size is 59 faculty. UT Physics ranks 34 with a faculty size of 29 at the time the ranking was made. To close the gap with the top 25, the department must grow in size. Of course, a bigger faculty does not guarantee a higher ranking, but it does help build critical mass in some of the key research areas, which in turn would put us in a better position to compete for large-scale grants and enhance our visibility. With new hires, we will expand the research capabilities on campus, which in turns attracts even better students and faculty to our campus.

For those of you who have been at UT long enough, the top 25 aspiration is not new. However, this time I am hearing a very consistent message from the campus administration and there are serious efforts underway to analyze the needs of the individual departments that would help them narrow the gap with the top 25 and to offer concrete assistance to the departments with, for instance, scholarships, new TA lines, faculty and staff positions, etc. Meanwhile, we have to do our part.

So where do we currently stand? The planning committee conducted a benchmark study in the spring, the results of which are published in the department’s 2012 strategic plan. It appears that our faculty are doing quite well,

compared to our peer institutions, in terms of scientific productivity, citations, and funding. Graduation rates for graduate students are on par with our peers, whereas the undergraduate graduation rate remains too low. Surprisingly, shortly after the study was concluded, we learned that AY2012 was in fact a record year in which 22 PhD students, 10 masters, and 15 bachelors have graduated. Whether these high numbers are a statistical fluctuation or represent an upward trend remains to be seen.

What must be done to further improve? One aspect is to further increase the research funding so that we will be able to increase our research output, generate more research assistantships (RAs), and move students more quickly into full-time RA positions. We need to modernize our course curriculum and evaluate the effectiveness of our teaching methods, as well as continue to innovate our teaching (see the article on Studio Physics on the front page). We need to increase the number of top-off stipends to recruit the best and the brightest students, and recognize faculty excellence through special or distinguished professorships.

I can go on, of course, and although it remains difficult how much funding will ultimately be available to propel this university to a higher ranking, I probably would have been much less enthusiastic applying for my new job if I didn’t believe that many of these objectives can be met. As the Chancellor has eloquently said many times, “the journey we take is as important as achieving the goal.” The strong support from faculty, staff, and university administration indeed makes me feel quite optimistic that as a department, we stand to reap great benefits from the top 25 initiative.

its equipment. With the growth in introductory physics enrollment, we couldn't handle the numbers."

Required Rethinking

Physics Professor Marianne Breinig taught Modern Physics, one of the first physics courses presented in the Studio Physics format.

"Studio physics requires rethinking how you're going to present the material so that it all makes sense," she said. "It's student-centered and interactive. You rethink how you present material, adding interactions and thinking about what you want to emphasize. The curriculum itself doesn't really change, but how you present the material does."

Currently Elston is teaching Physics 135, an introductory physics course for science and math majors (where students tackled the afore-mentioned coffee filter question). He uses the same SCALE-UP approach in practice at North Carolina State, which is a very specific model. His students spend five hours in class per week, with an emphasis on rigorous problem-solving using interactive instruction, peer instruction, and computer applications. They are required to read material before class, complete online homework assignments, keep a homework journal, and work in close collaboration in the lab, where he walks around the room and offers help as needed.

Elston's course places a strong emphasis on group work, and his syllabus includes a bonus for "teamship." If the average test score of any group is 80 percent or better, each team member gets an extra five points. In the class meeting before an exam he also gives the groups a challenging problem they can work on together. They'll see the same problem (or a remarkably similar one) on the test.

"At first I thought it was sort of cheating," he said, "but it's still a discriminating exam problem. Not everyone acs it."

His students work in groups of three with rotating assignments as manager, recorder, and skeptic. This semester he has allowed students to work in self-selected groups, although next term he plans to assign groups and then let the students compare the two approaches. There are different criteria for building teams, although the standard for SCALE-UP has been to put together three students with varying levels of capability, representing a mix of gender and ethnicity.

Once, however, Elston said his enrollment worked out so that he needed to assign a group of three women with differing academic strengths. Over the course of the term the weaker students rose to the top and ultimately, the group had far and away the best grades in the class.

"It was neat to see that happen," he said. The idea is that stronger students learn by teaching, and students who struggle a bit more with the material have the benefit of a fellow student as tutor. Another method is to assign teams based on a Myers-Briggs indicator that would group students by their different cognitive approaches to problem-solving, which gives a team three different ways to find a solution if they get stuck.

This emphasis on collaboration is a major departure for students who like to go unnoticed in a classroom, Elston said, but "the students who really want to learn benefit from this approach because they get individual attention." While this flipped classroom idea asks more of students, adapting the curriculum to the Studio Physics approach isn't necessarily a simple task for faculty members either.

"It takes commitment," Elston said. "At least initially, it's more work. It takes a different mindset than a traditional way of teaching physics."

He explained that for any professor there is sometimes the temptation to fall into a pattern of teaching the way you were taught, particularly if students don't seem to be grasping the material.

Students in Professor Stuart Elston's SCALE-UP physics class can earn points for "teamship," where any team with an average of 80 percent or better on an exam earns each student an extra five points. This emphasis on teamwork is a cornerstone of the Studio Physics program.





Students in Dr. Marianne Breinig's Physics 222 class consult on a problem related to interference patterns before they answer using clickers. This blended approach incorporating online, classroom, and Studio Physics elements is one of the many learning environments available to students enrolled in UT physics courses.

"It's so easy to mimic what your professors did," he said, "even if it's wrong."

Different Ways of Learning

Although it has a strong following among UT physics students now, Studio Physics did not have an auspicious introduction to the department.

"The first time I did it, they hated it," Breinig said. She explained that students not only had one less lecture, they also didn't have a traditional lab, an element that met with resistance because "they wanted to get in and get out in about an hour."

The results, however, changed their minds about the method.

"They got better grades," she said. "Now they really like how it works. I give them more ways of showing me that they learned something—that they actually mastered the material. A lot of students seem to want to go into Studio Physics classes."

This flexibility extends to the method itself, which is not a one-size-fits-all teaching tool.

"A few years back when Studio Physics began to catch on, people wanted everyone to go full-in," Breinig said. "After some time, even the people who pioneered it found

that is too expensive. Many people went to a mixture. There are lots of different models."

Breinig is currently teaching Physics 222, Elements of Physics II, which pulls together various elements from Studio Physics and other teaching methods.

"I bought into this flipped classroom," she said. Students read the course assignments online and then do a pre-lab exercise, with homework assignments due each week. Once a week they attend a studio session, where, under the guidance of teaching assistants, they work with one another on computer simulations, demonstrations, and problems to help reinforce the concepts they are learning—diffraction and interference, for example, or seeing light as both a wave and a particle. Their second weekly meeting is in a large lecture hall where they're presented with a problem that reviews the week's topic. They can discuss the problem with each other or ask Breinig or her student assistant for help, and then register their answers using clickers.

Breinig writes the course outline and all the questions, but said that in general, she doesn't lecture at all. She described her class as "a work in progress," as she determines what's most useful to help students understand the material.

As an alternative to the SCALE-UP model in Elston's class, Breinig also teaches Physics 135-136, but as an online course.

"What I do in my online course is different from what other people do. I do it totally asynchronous," she said. There are online experiments and homework assignments, with a schedule of deadlines. She sends a reminder before every due date, and students have the flexibility to work from home, from the library, or anywhere they can get Internet access. The only time she sees them is for exams. This option is especially attractive for students who may not have the time to dedicate to something like a SCALE-UP course, such as those who work full-time or non-traditional students who have families or other responsibilities.

"There are some people who otherwise wouldn't take a physics course," she said.

Breinig said the online course earns student evaluations comparable to those for Studio Physics and presents students with yet another choice. The department still offers courses with traditional lectures and lab, along with Studio Physics, online courses, or classes that could be characterized as "hybrids," which combine elements of all three. For students enrolled in UT physics classes, there is a full menu of options.

"I think this is the great thing about our department," Breinig said. "We give students different ways of learning things."

Managing Expectations

Gerald Ragghianti's job requires both sophisticated computing skills and a fair amount of diplomatic mastery. As a senior computer services technician with UT's Newton Program, he orchestrates shared usage of high-performance computing resources, allowing campus scientists to worry

less about hardware and focus more on their research. He is a two-time graduate of the physics department, and his work with large collaborations

has given him valuable experience not only in large-scale computing, but also in encouraging several different stakeholders to, as he described it, "play nice."

Diplomacy is a natural fit for the even-tempered Ragghianti, who grew up in Bartlett, Tennessee, and first came to UT—and the physics department—as a high school student via the Governor's School for the Sciences.

"I was always inquisitive," he said. "Primarily I chose physics because the description of it was that it was sort of challenging: a 'You're going to have a lot of fun, but you're going to have to do some work too,' kind of thing. I guess I was up for a challenge."

The Governor's School experience was a major factor in recruiting him to UT, where he finished a bachelor's degree in physics in 2002. He then entered the master's program, working with Dr. Stefan Spanier on the BaBar experiment, a project devoted to understanding the behavior of elementary particles. In addition to investigating physical phenomena, Ragghianti also learned to tackle computing issues in a large scientific collaboration.

"We were investigating CP asymmetry, but there were a lot of computing challenges associated with that project," he said. "We ran a center here for BaBar that produced Monte Carlo simulations for probably four years straight on a computer cluster that we built. That's where I got most of my experience."

He also worked on the computing infrastructure for the Compact Muon Solenoid detector, or CMS, part of the Large Hadron Collider and the hunt for the Higgs Boson.

"I was very happy to be part of that," he said of the latter, which made headlines this summer with the detection of a new particle thought to be the elusive Higgs. "Although I'm actually a little more proud of my thesis work for BaBar because it was a lot more hands-on physics, whereas I was primarily doing computing for the LHC work."

It was his introduction to high-performance computing, or HPC, during graduate school that helped lay the foundation for a full-time position with the university after he finished a master's degree in 2006.

"I was very lucky that UT created a position for high-performance computing right about the time I graduated," he said. "I had the opportunity to continue working with Stefan but also to expand and work all across campus and support similar computational challenges in other fields."

Good Computing Citizenship

Ragghianti works primarily on the university's Newton HPC Program, which supports high-performance computing by allowing UT researchers to participate in one of two ways: by free use of any available resources or by priority use if they contribute hardware or funding.

"What we try to do is basically take away all the infrastructure challenges associated with high-performance computing and do as much as we can to make the scientists' job as easy as possible," Ragghianti explained. "We buy computer clusters on their behalf, manage them, and then make them available the same way as if they had built them themselves. We want them to be able to concentrate on their domain-specific applications, data analysis, and code, and not have to worry about things that aren't necessarily in their skill set, like managing a huge computer cluster."

"Getting people to play nice together is always a challenge when you're dealing with multi-user environments like we have on Newton," he continued. "We try as much as possible to make it very easy for people to be good computing citizens. When you're sharing resources it's a little bit different than when you're running on your desktop by yourself."

While Newton doesn't require a buy-in, researchers who want guaranteed access provide funds or equipment, and

Alumnus Profile



Gerald Ragghianti first came to UT through the Governor's School Program as a high school student. He holds both bachelor's and master's degrees from the physics department, and now works with UT's Newton High-Performance Computing Program.

"My original intent in going through physics was that it wouldn't pigeon-hole me and limit me in what I decided to do later, and I think that's worked out well. I'm really lucky that I really enjoy what I'm doing right now."

Meet Dr. Christine Natrass

It's just shy of 6:00 p.m. on a Monday in late October and Dr. Christine Natrass is answering an e-mail request for an interview, almost as quickly as it arrives. Rather than scheduling something for later, she writes, she could do it right now, if that will work. In only her third month in a new job, Natrass is judicious about managing her time. She joined the physics faculty as an assistant professor on August 1, but with an impressive list of accomplishments in her wake and a clear vision of what she wants to achieve in the future, she is already off to an excellent start.

Natrass has actually been part of the physics department since 2009, when she joined Dr. Soren Sorensen's research group in ultra-relativistic heavy ion physics as a postdoc. She came to Knoxville from Yale University after completing her doctoral research on the STAR detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. She has been extremely active in major research collaborations since her graduate school days, working on STAR for six years and then

doubling up with contributions to both ALICE (A Large Ion Collider Experiment) at CERN and the PHENIX collaboration at Brookhaven. In May 2008 Brookhaven rewarded her efforts with the Gertude Goldhaber Prize, which recognizes substantial promise and accomplishment by a female graduate student in physics.

Though she's still involved with PHENIX, her primary research focus is now with ALICE, which takes advantage of the powerful particle collisions provided by the Large Hadron Collider. She works specifically with the experiment's electromagnetic calorimeter, or EMCal. Tipping the scale at 80 tons, the EMCal was installed in its entirety in January 2012; Natrass was there helping commission electronics. The EMCal will allow scientists to measure the properties of jets: sprays of

New Faculty

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Ragghianti makes sure that resources are assigned fairly within that model, which he said has worked out very well. Another advantage of the operation is its efficiency: he's the only full-time employee, and he supervises a half-time graduate assistant.

"Other than that, we leverage the resources that the Office of Information Technology offers to the whole campus," he said, including Help Desk and Network services. "We can run this very large system and offer all these services associated with it, but we don't require a whole lot of manpower to do so. I spend about as much time running a 4,000 CPU system as I did just running the one for Stefan."

Ragghianti is also the chief technology officer and administrator of PolyHub, a program funded by the National Science Foundation. Dr. Brian Edwards of the university's Department of Chemical and Biomolecular Engineering is the principal investigator on this project, which is an engineering virtual organization connecting researchers

from all over the world who study polymer dynamics.

"I was invited to become a part of that shortly after I started working on Newton," Ragghianti said. "It's a cross-disciplinary collaboration—multi-institution—for polymer dynamics. It primarily deals with how do we get these scientists working together if they work at disparate institutions; how can they share data and computational resources."

Working in computing is a natural extension of his studies in physics, a major he chose in part because of the flexibility it offered.

"My original intent in going through physics was that it wouldn't pigeon-hole me and limit me in what I decided to do later," he said, "and I think that's worked out well. I'm really lucky that I really enjoy what I'm doing right now. And part of the reason is that I'm not doing the same thing all the time. I do a little bit of computing, a little bit of computer science, a little bit of consulting—just general computational methods for disciplines all over science and engineering."

He also has a lot of freedom in his job, and, he said, the opportunity "to chart the path and lead the university in high-performance computing.

"Working for the university is really great," he continued. "The academic, scholarly environment is very stimulating. There are a lot of opportunities that aren't specifically related to my field."

Ragghianti availed himself of one such opportunity last summer when he spent a month in Beijing teaching at the Summer English Camp at Tsinghua University through the Ready for the World program. While he's adept at running 4,000 CPUs of power, Ragghianti enjoys spending his off-hours with decidedly low-tech avocations, like carpentry, for example. He also kindly declines any offers to be the on-call tech support for friends and family.

"I make it a point of letting them know that I would be happy to help them fix their supercomputer, but I know absolutely nothing about laptops," he said, laughing. "That's worked well for me."



Dr. Christine Natrass joined the faculty as an assistant professor in August. Her research takes her to the Large Hadron Collider at CERN, where she studies the properties of jets: sprays of high-energy elementary particles that result from the fragmentation of quarks or gluons. She is also committed to outreach and has been heavily involved with the Southeastern Conference for Undergraduate Women in Physics.

high-energy elementary particles that result from the fragmentation of quarks or gluons.

By calculating the energy and momentum of all particles in a jet, scientists like Natrass learn more about the properties of quarks, and consequently the quark gluon plasma, or QGP—a kind of primordial soup present when the universe was born. She is also a co-leader on the ALICE analysis working group on transverse energy.

Natrass has already begun building her research group with the addition of a postdoc and a graduate student, and will likely head to CERN next summer to continue her studies. This semester, however, she's gotten to spend more time at home now that her responsibilities have mushroomed somewhat with a faculty position. Among those requirements is teaching Modern Physics for the Fall 2012 term.

The classroom is hardly new ground for her: she was a teaching assistant every fall and spring semester in graduate school, covering courses for both majors and non-majors, and is also a certified tutor. In 2011 and 2012 she was a discussion leader for UT's Life of the Mind freshman seminar. Still, she said she enjoys building on her experience and learning from what works and what doesn't to improve her teaching.

"I'm going for no disasters," Natrass said, smiling, explaining that a less than perfectly-worded problem on a homework assignment, for example, is much easier to rectify than one on an exam.

She said she has learned that the key to successful teaching is to be clear about expectations, stick to them, and be fair. Next spring she'll be teaching Physics 221, a required course for pre-med majors, and her own undergraduate experience gives her a bit of an advantage when dealing with these typically competitive students. In 2003 Natrass graduated with a bachelor's degree from Colorado State University in physics, biochemistry, and physical science; so having sat through classes with future doctors, she said she understands their mindset somewhat. And she acknowledges that she was fairly driven in her own right.

"I was not an easy student," she said, laughing. "I'm sure whatever they give me, I'll deserve."

Dovetailing with her teaching and research interests is a strong commitment to outreach. She's been a blogger for the ALICE collaboration, a volunteer guide for public tours at Brookhaven National Laboratory, and

has co-organized a BNL workshop on diversity.

Of particular importance to her is the encouragement of girls and young women to pursue careers in science (she herself was named the American Physical Society's Woman Physicist of the Month for May 2012). Natrass became involved with the Conference for Undergraduate Women in Physics (CUWP) while at Yale and since moving south has been heavily involved with its Southeastern counterpart (SCUWP), serving as chair of the organizing committee for the 2012 meeting, hosted at UT. She is also interested in working on a children's book about high energy physics and has submitted a grant to the National Science Foundation to support work with a colleague at the Pratt Institute to produce some videos about ALICE.

While Natrass said some of these projects are perhaps more fun than they are "tenure-building," she does them not only because she enjoys them, but also because they serve an important purpose in justifying the existence of scientific research and spending public money on large projects.

"There is an element of professional responsibility in presenting the products of that research in a way that's accessible to the public," she said.

When she isn't working on physics, Natrass pursues a myriad of interests: running, cooking, gardening, and spending time exploring the outdoors—a passion she shares with her husband, Ondrej Chvala, a research assistant professor in UT's Department of Nuclear Engineering. These days, there's a bit less time for those avocations: in October alone she had talks scheduled at Ole Miss and Colorado State. She also has lectures to prepare, and start-up money to budget.

Natrass said that among her challenges as an assistant professor is time management—balancing research, teaching, outreach, conferences, talks, and other faculty requirements. From the look of things, she is clearly getting the hang of it.

Condensed Matter Physics at UT

Long before anyone was calling it condensed matter physics, the science behind solid materials was a driver in scientific discovery and industrial innovation. The simple glasses ancient Mesopotamians learned to make from soda ash are used even now in windows and wine bottles. The revelation that semiconductors, materials in between insulators and metals, could conduct electrical current under appropriate circumstances gave rise to the billion-dollar electronics industry that today underscores the way we communicate. In recent years, the study of materials and the physical phenomena that govern their behavior has grown ever more sophisticated, encompassing examples like high critical temperature superconductors or nanowires: tiny conductors with length scales in the nanometer. And through experiment and theory, UT's condensed matter physicists are helping write the next chapter of this rich and complex story.

Zero-Resistance Materials

One area of keen interest in the current scientific climate is superconductivity. The possibility of zero-resistance electrical current has huge implications for environmental, energy, and a host of other applications, but only if this phenomenon could occur at ambient temperature. While scientists learned a century ago that certain materials possess the structure and properties to become superconductors, the road to capitalizing on that potential has not been so easy to navigate. Superconductivity in any material appears just below a given critical temperature, or T_c . Even in the so-called high-temperature superconductors discovered in the mid-



Pengcheng Dai

1980s, this temperature has been far too low to be practical for common applications. Yet for 20 years, these copper and oxygen compounds (called cuprates) provided the best test cases for studying the origins of superconductivity, with growing consensus that magnetism plays a key role. That all changed in 2008 when a new class of materials emerged made from iron and other elements such as arsenic and selenium.

Scientists the world over have been working at a rapid pace to reveal the properties of these compounds, and from the beginning UT's physicists have made significant contributions to understanding how they work. Professor Pengcheng Dai's group discovered the anti-ferromagnetic order in the parent compound of iron pnictide superconductors and published these key findings in *Nature* in May 2008. That paper has more than 900 citations, and his group has followed up their work with a prodigious amount of additional research. Assistant

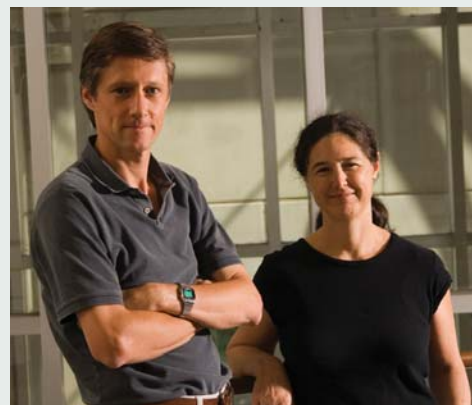
Professor Norman Mannella found that these pnictide materials do not belong to the unusual class of doped Mott insulators to which the high temperature superconductors do. This result was particularly significant, because both the pnictide and cuprate superconductors are proximal to antiferromagnetic insulators, and it is believed that Mott physics plays a crucial role in attaining high superconducting transition temperatures in the cuprates.

This past October, Dai and Distinguished Physics Professor Elbio Dagotto, working with their colleague Professor Jiangping Hu from the Chinese Academy of Sciences and Purdue University, reviewed the status of iron-arsenic

superconductors for *Nature Physics* in a paper entitled "Magnetism and its

Microscopic Origin in Iron-Based High-Temperature Superconductors." In examining the past four years' worth of research—both theory and experiment—Dai, Hu, and Dagotto compare iron-based superconductors with the cuprates, as well as with one another, paying specific attention to the origin of magnetism in these materials. They conclude that no simple explanation applies across the board, as iron-based superconductors can actually be divided into three families, each with potentially different magnetic roots.

Among those differences is a varying strength in electronic correlations, another research interest of UT's CMP group. More recently, in collaboration with Professors Nan Lin Wang of Purdue and Hideo Hosono of the Tokyo Institute



Elbio Dagotto and Adriana Moreo

of Technology (whose group discovered iron-based superconductors), Dai co-edited the book *Iron-Based Superconductors: Materials, Properties and Mechanisms*, which summarizes the progress and issues in the field. He also wrote a chapter for the text, which was published in November by the Pan Stanford Publishing Company. Dagotto has also worked actively in this field, and produced an invited review for the prestigious *Reviews of Modern Physics* that will appear in print soon.

One avenue the CMP group follows in these endeavors is the study of strongly correlated electronic systems. In these

Research Spotlight

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configurations, simple building blocks form large ensembles that exhibit useful and interesting properties including high temperature superconductivity, as well as colossal magneto-resistance, or CMR—where the application of a magnetic field can change a material’s resistance by several orders of magnitude. Dagotto co-wrote a book chapter on these systems when they are prepared in the form of artificial superlattices. The text, *Multifunctional Oxide Heterostructures*, was published in August by Oxford University Press, with Dagotto serving as one of book’s four editors. He and Professor Adriana Moreo have built a research group dedicated to the study of strongly correlated electrons, and their recent studies have focused on superconducting iron selenides, oxide interfaces, and other materials using sophisticated theoretical models and computational techniques to help describe the phase diagram of these materials. Earlier this year, Mannella won a Faculty Early Career Development (CAREER) Grant from the National Science Foundation to study complex electron systems from the experimental side of things (see the *CrossSections* feature at http://www.phys.utk.edu/xsections/xsections_S2012.pdf). He is also interested in exploring materials for energy storage, as well as technological applications such as sensors, electronics, and displays.



Norman Mannella

Other members of UT’s CMP faculty are investigating similarly interesting research areas. Professor Hanno Weitering studies nanoscale superconductors and metallic nanowires. He is also leading efforts to develop doped transition metal oxide materials for photovoltaics and photocatalysis—specifically using ultrathin films: materials measuring only five to 20 atoms thick. Most recently, he acquired a \$1.3M oxide molecular beam epitaxy growth system that is being dedicated to the growth of multifunctional oxide heterostructures. Weitering, who became physics department head on August 1, is also the deputy director of the UT-Oak Ridge National Laboratory Joint Institute for Advanced Materials



Hanno Weitering

(JIAM). Dai and Mannella are also research affiliates with JIAM, which is dedicated to the development of ever-more sophisticated materials in response to demands from fields like electronics, medicine, and transportation. In the future, this institute will be housed in a state-of-art facility on the university’s Cherokee Farm research campus.



Adolfo Eguiluz

Such efforts are further bolstered by the theory work of Professors Adolfo Eguiluz and John Quinn, who study electronic structure and interactions in condensed matter systems. Eguiluz develops self-consistent ab-initio theoretical and computational methods for studying the ground state and excited state properties of complex, correlated electron materials, while Quinn has made strides in understanding such scientific puzzles as



John Quinn

the fractional Quantum Hall effect, wherein many electrons working in tandem can actually create new particles with a charge that is smaller than that of any of the individual electrons.

The newest addition to the CMP group is Assistant Professor Haidong Zhou (see *related article on page 11*). He joined the faculty in August and is already building a laboratory to grow single crystals, whose repetitive lattice structure make them good candidates for revealing a material’s properties. With an ever-increasing demand for such sample materials, the ability to grow these crystals on campus is yet another asset of UT’s program, whose focus falls right in line with national priorities.

The National Science Foundation has outlined a number of questions that condensed matter physics research should answer, including “How and why do complex macroscopic phenomena emerge from simple interacting microscopic constituents?” and “What is the physics behind the behavior of matter confined to the nanoscale in one or more dimensions?” With on-campus computing and laboratory resources and collaborative efforts that span the globe, the CMP group at UT is at the forefront of addressing these scientific queries.

See more features about the CMP group, and visit individual research pages, by visiting <http://www.phys.utk.edu/research/cmp/index.html>.



Congratulations to Dr. Pengcheng Dai of the Condensed Matter Group, who was recently elected a Fellow of the American Association for the Advancement of Science “for distinguished contributions to the understanding of the magnetic properties in copper and iron-based high temperature superconductors, heavy fermion metals and colossal magnetoresistance manganites.”

Haidong Zhou: The Crystal Grower

Haidong Zhou is by nature an optimist—quick to smile and always cheerful. But when it comes to physics, he is also willing to consider what he calls a little “risky business” to make new discoveries in materials and their properties.

Zhou joined the physics faculty on August 1 as an assistant professor. He came to UT from the National High Magnetic Field Lab in Tallahassee, Florida, where he worked as a postdoc and assistant scholar/scientist. There he honed his considerable skills to become a well-respected crystal grower, a talent that he said probably got him appointed in the first place.

“I think the main reason I was hired at NHMFL was to grow single crystals for high magnetic field measurements,” he said.

Single crystals are an important component of condensed matter physics by virtue of their predictable architecture. Atoms like to organize in a lattice-like structure, and in a single crystal, all those lattices are oriented in the same direction. Zhou explained these crystals are also more dense and solid than their polycrystalline counterparts, making them useful for measuring a material’s properties. His field of expertise is growing single crystals using an image furnace, which creates a material from selected elements using precisely-controlled high heat. It can take days to make a single crystal, and Zhou has grown and studied a variety of them. He uses complementary techniques to investigate characteristics such as their structure, electronic and magnetic properties, or how they respond to a magnetic field. His main interest lies in designing, creating, and describing new materials with intriguing physical properties and potential applications. This is the basis for novel physics, which gives rise to new materials and, ultimately, new technology. Deciding what direction to take requires some planning, however.

“I have the freedom to work with all kinds of samples, but time is limited,” Zhou said. So he decides what properties are the most interesting—superconductivity, for example—and then chooses the best materials as candidates for study.

“It really depends on what kind of chemistry you need to make the sample,” he said.

He explained that while he always has a lot of projects in mind, when deciding what to work on he tries to strike a balance between exploration and intuition: sometimes sticking to fairly predictable territory and other times blazing a new trail.

“I divide my time between working with known materials and some risky business,” he said, smiling.

For example, if he’s working on an experiment and he gets some good preliminary results, the optimistic Zhou said he’s confident “things will work out,” which

is good for building a research program and publishing results. But there’s always the quest for discovery: either by looking at well-known materials in a different light using modern technology, or creating new materials altogether. In that case, he said, “I define a strategy and then I look at the periodic table and I try to make something.”

Zhou has on-campus research space, for which he is currently acquiring the equipment needed to grow and characterize single crystal samples. In the interim, he has access to furnaces and other equipment in Professor Pengcheng Dai’s lab. He can grow crystals for his own experiments or provide samples for his wide network of collaborators, including fellow UT scientists and researchers at Oak Ridge National Laboratory and all over the world. He will also work on experiments at larger national and international facilities, but said the key difference between those studies and the work he will do in his campus lab is that the latter involves educating students. He already has a graduate student who has started to grow crystals, and his interest in learning and teaching goes back to his own experience as a student and the professors who inspired him.

Zhou earned both bachelor’s and master’s degrees at the University of Science and Technology of China, where his master’s thesis was on colossal magnetoresistance (CMR)

Assistant Professor Haidong Zhou joined the faculty on August 1. He specializes in growing single crystals, and his main research interest lies in designing, creating, and describing new materials with intriguing physical properties and potential applications.

materials. This interest in condensed matter physics was what led him to the United States for his doctoral work.

“In China in 2000, we didn’t have the ability to do these single crystal growths,” he said, so he moved to the University of Texas where both the necessary equipment and ability were available. He earned the Ph.D. in December 2005 working with advisor and mentor

New Faculty



Continued on page 12

The Physics Top 10 List

In the Fall Of 2010, *CrossSections* began highlighting the Top 10 Most-Cited Papers from our department, with insight from the authors, beginning with Number 10. These papers show the breadth and influence of the physics department's research program.

#6

Title: $K\bar{K}$ Molecules

Authors: John Weinstein and Nathan Isgur

Journal: *Physical Review D* **41**, 2236 (1990)

Times Cited: 430 (as of 11/5/2012)

had attractive potentials while the other “exotic” states had repulsive potentials. These meson-meson potentials were manifestations of underlying quark exchange processes.

Even more exciting, the $K\bar{K}$ potential was strong enough to bind them into “ $K\bar{K}$ Molecules,” two lightly bound kaons about 3 kaon radii apart.

Discovered in the 1950s, the $S^*(975)$ and $\delta(980)$ scalar resonances were long thought to be very badly behaved $L=1, S=1, J=0, q\bar{q}$ states. Interpreting them as $K\bar{K}$ bound states solved literally dozens of experimental anomalies in spectroscopy and in strong, weak, and electromagnetic meson decays.

These meson-meson potentials were later combined with $q\bar{q}$ annihilation and creation processes to construct the “Multichannel Quark Model,” unifying meson-meson scattering with meson spectroscopy and avoiding the fantastically poor eigenvalue approximation that hadronic systems with lifetimes of order 10^{-23} seconds can be treated as being long-lived. Amongst its many successes: while long-lived resonances had Breit-Wigner line shapes, short-lived resonances did not and even appeared with different masses in different decay channels.

In retrospect it's not really surprising that, rather than forming a third class of hadron as other contemporary studies were predicting, or not interacting at all as we had presupposed, $qq\bar{q}\bar{q}$ systems form a second, though very sparsely populated, periodic table with two confirmed “elements.”



Summary

Courtesy of Dr. John Weinstein
President, Inclined Elevation
Bracebridge, Ontario, Canada

Thirty years ago Nathan Isgur and I were studying the $qq\bar{q}\bar{q}$ system in the Isgur-Karl quark model. This model considered non-relativistic quarks interacting via an $SU(3)$ generalization of the $U(1)$ electron-electron interaction and had successfully accounted for a vast array of meson and baryon data including masses, lifetimes and production and decay properties. Applied to the 6 quark system, it even reproduced the properties of the deuteron.

We were expecting that the $qq\bar{q}\bar{q}$ ground state would be two non-interacting $q\bar{q}$ mesons and were delighted to discover instead that the meson-meson states with single meson quantum numbers (called “cryptoexotics”)

Haidong Zhou, continued from page 11

Dr. John B. Goodenough. During his tenure at Texas and later at NHMFL he supervised both undergraduate and graduate students, and here at UT he will teach Physics 231 (Electricity and Magnetism) for the Spring 2013 semester.

Part of what intrigues Zhou about teaching is the opportunity to go beyond equations and textbooks and look at the bigger picture—the continuum of scientific discovery. He said he could lecture on Gauss's Law, for example, but he might also share a bit about the man behind it, Carl Friedrich Gauss, and share a more personal glimpse of what sort of person he was, and how the ideas of pioneers like him are still relevant.

“I like these kinds of small stories,” he said, and he would like lectures to include a few tidbits of something

different. Down the road he would like to design his own course: perhaps one focusing on the relationship between physics and materials with examples like high-temperature superconductors, graphene, and topological insulators, with an emphasis on new technology and applications.

In his life outside physics, Zhou is an avid soccer player and sports fan. He and his wife Feng Liu, who just completed her master's degree in oil painting, are settling in to life in Knoxville as he makes the transition to an academic setting. Part of why he pursued a professorship, he said, was “the chance to educate young people and transfer what I know to the next generation.”

Ever the optimist, he added with a cheerful grin, “I hope they like it.”

Graduate Physics Society News

At the end of the Spring 2012 semester, the graduate physics students elected the following as the 2012-2013 Graduate Physics Society (GPS) officers: Rebecca Scott (President), Robert Potts (Vice President), and Meagan White (Secretary/Treasurer). Since the elections, GPS has worked to be more involved with welcoming the incoming graduate students and bringing the graduate students together as a group. In

early June, GPS held a social gathering to encourage first-year graduate students to seek out older graduate students for advice on how to best prepare for the qualifying exam. In August, GPS (with the excellent help of Chrisanne Romeo) worked to welcome the new graduate students by hosting an informal information session about available classes, teaching advice, and various department policies. This fall, GPS held some social gatherings to provide students with a much-needed break from studying. Currently, GPS is encouraging graduate students to send in research posters to be posted throughout the Nielsen Physics Building and also to give presentations to their peers about their research. Looking forward, GPS is working to arrange volunteering opportunities and seminars on various types of programming. — *Courtesy of Robert Potts*



The Graduate Physics Society welcomed new students into the program this fall with an informational session to answer questions about coursework, teaching duties, and grad student life in UT Physics.

Gadget Girls Visit UT Physics

Undergraduate Physics Major Emily Finan taught area Girl Scouts that Jell-O and optics can actually work together as part of the Gadget Girl Adventures in STEM program, hosted by UT on November 17. UT works with the Girl Scout Council of the Southern Appalachians to encourage and inspire girls in grades 6-8 to pursue careers in Science, Technology, Engineering and Math (STEM) fields. Finan, a Talley Scholarship recipient, works with Research Assistant Professor Christine Cheney in Dr. Norman Mannella's lab.



Faculty

When CERN announced on July 4 that they had observed the clear signs of a new particle that could be the elusive Higgs Boson, it meant **Dr. Stefan Spanier** spent his holiday doing interviews with various local press outlets. His research group has been part of the hunt for the Higgs for the past six years, working with the international collaboration that built and maintains the Large Hadron Collider's Compact Muon Solenoid detector. See the full feature article on the physics Web site at: http://www.phys.utk.edu/news/2012/news_higgs_07042012.html.

Professor Witek Nazarewicz was honored with the 2012 Oak Ridge National Laboratory Distinguished Scientist Award at their annual Awards Night celebration on November 16.

Nazarewicz was recognized “for his foundational work in developing and applying nuclear density functional theory, resulting in a comprehensive theoretical framework for the physics of exotic nuclei and tremendous advances in our understanding of them, and for his pivotal role in the promotion of radioactive beam physics in the United States.”

Alumni

» **Roy Dar** (Ph.D, 2011) is a Postdoctoral Fellow with the Weinberger Laboratory at the Gladstone Institute for Virology and Immunology at the University of California, San Francisco.

» **Merek Austin Chertkow** (Ph.D., 2012) is working for SpaceX in California, a company that successfully sent its Dragon

spacecraft to the International Space Station and back home in October.

» **Shannon Mahurin** (Ph.D., 2000) and his wife Tasha have chronicled local stories and legends in the book *South Knoxville*, which was released on September 10. The couple spent roughly 18 months working on the project, which includes photographs and stories about the southern part of town.

» **James Wicker** (Ph.D., 2006) spent two weeks this summer on the newspaper staff for the International Astronomical Union's General Assembly in Beijing, this year called “Inquiries of Heaven.” Held every three years, it's the largest meeting of astronomers worldwide. Wicker, whose regular job is working as an editor for the journal *Research in Astronomy and Astrophysics*, helped cover the action.

Physics Family Photos

The UT Society of Physics Students (with advisor Professor Jon Levin) travelled to Orlando for the Quadrennial Physics Congress, held November 8-12. They attended plenary talks by such esteemed scientists as Dr. Jocelyn Bell Burnell and Freeman Dyson, toured NASA's Kennedy Space Center, and availed themselves of workshops and poster sessions. UT SPS President Richard Prince was also elected Associate Zone Councilor for Zone 8.



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The physics department has several award and scholarship funds to support our vision of excellence in science education at both the undergraduate and graduate levels:

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If you would like more information on how to make a gift or a pledge to any of these funds, please contact either the physics department or the College of Arts and Sciences Office of Development at (865) 974-2365. You can also donate online by going to: <http://www.artsci.utk.edu/> and clicking on "Support the College."



When NBC's *Today Show* broadcast from the UT campus on September 19, physics staffers Maria Fawver and Showni Medlin-Crump (left) were happy to show their Big Orange spirit, as was Chrisanne Romeo (right), whose desk was temporarily overtaken by a familiar university mascot.

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