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An introduction to the theme issue

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GUEST EDITORIAL

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> "Ladies and Gentlemen, we have detected gravitational waves. We did it."[1]

When the topic for the 2016 Gordon Research Conference (GRC) on physics research and education was selected in 2012, the timing seemed appropriate. Albert Einstein had explained in 1916 how his general theory of relativity predicted the existence of gravitational waves. Four years ago we could not have imagined that just a few months before this conference the detection of gravitational waves from the collision of two black holes would be announced. Thus, while the physics and education GRC is unique among Gordon Conferences, this one will be even more special in that it will be the first conference to bring together researchers and educators so shortly after a major discovery in the field. The increase in interest in fundamental science generated by this historic announcement is already evident, and the conference will provide a great opportunity to discuss better ways to teach students about relativity and gravitation.

Fundamental physics, teaching, and educational research related to gravity and relativity continue to expand both our understanding of nature and our knowledge about how we can teach them to a broad spectrum of students and the general public. Applications and technologies, such as the global positioning system, have shown that concepts that were once thought to be only of academic interest have far reaching consequences that affect and influence the scientific community, the education of future scientists and engineers, and the general population. As a result, physics education researchers have focused some attention on the teaching and learning of relativity (special and general) and gravitation. However, the level of education research and development is this area has been somewhat less than that in other contemporary physics topics (such as quantum physics). Thus, this GRC is an opportunity to motivate additional efforts in this important topic and to build on the momentum generated by the LIGO announcement.

When this theme issue and the related GRC were conceived almost four years ago, our thoughts were that contemporary ideas in physics were still not making it into the mainstream of instruction as quickly as we would like. Certainly, quantum physics, special relativity, and some other ideas were being learned by upper-level physics undergraduates and perhaps even by some beginning college students. However, other topics were barely "creeping" into the curriculum of any students below the graduate level.

Close to the top of many lists of topics that needed more exposure were gravitation and general relativity. By the time this conference would occur Albert Einstein would have published his first paper on gravitation and general relativity[2] over 100 years ago—ten years after he had introduced special relativity. That fact alone seemed to be an appropriate reason to focus an issue of the *American Journal of Physics* and a Gordon Conference on physics research and education on these topics.

However, as the planning for the conference was in its final stages it started becoming clear that the focus on general relativity and gravitation might have a greater impact than anticipated on the physics and physics education communities. On the day after we began writing this editorial the LIGO Scientific Collaboration announced that

> The LIGO detectors have observed gravitational waves from the merger of two stellar-mass black holes. The detected waveform matches the predictions of general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.[3]

This major step in our understanding of space-time will pique the interest of today's students in a way that we could not have anticipated.

Of course, general relativity usually comes with significant mathematical baggage. For many students (and perhaps some instructors) the mathematics can be an insurmountable barrier. When we as teachers and researchers are faced with such a situation, we frequently turn to some type of visualization. Perhaps the most famous for gravitation is the stretched rubber sheet to represent two-dimensional space. Place a heavy mass on the sheet and we "warp" the space; a small ball will then go into orbit for a short time before being "attracted" to the heavy mass. Such a visualization is a good start but does not necessarily lead to deep understanding.

In this issue, we have several approaches that describe visualizations that can help students go deeper. One uses items as simple as a wall map of Earth while another involves computer technology. Today, we have a large number of tools that we can utilize to help our students learn these rather abstract ideas.

Years of research on how students learn physics tells us that visualizations by themselves are not sufficient. The students need to be actively involved in their learning. Certainly, the two visualizations mentioned above lend themselves well to contemporary evidence-based learning techniques. So do several other papers described here. Some of them provide tutorials or worksheets to guide students through aspects of gravitation theory.

In addition to the pedagogical focus of some papers in this issue, several authors advance knowledge in the field of relativity and provide all of us with new ways of thinking about the topic.

With the new research findings in gravitation and the general public interest generated in just the past few months, we must revisit the choice of mostly omitting gravitation and relativity from parts of the physics curriculum. We can make aspects of gravitation accessible to a broad spectrum of students and the public. The Gordon Conference in June will provide an opportunity for gravity researchers, educators, and physics education researchers to explore ways to accomplish this task. Further, the conference will offer the opportunity to discuss the gravitational wave discovery with people who were part of the process of that discovery. All physics faculty and graduate students are invited to apply to participate. We particularly encourage those from underrepresented groups to submit an application.[4]

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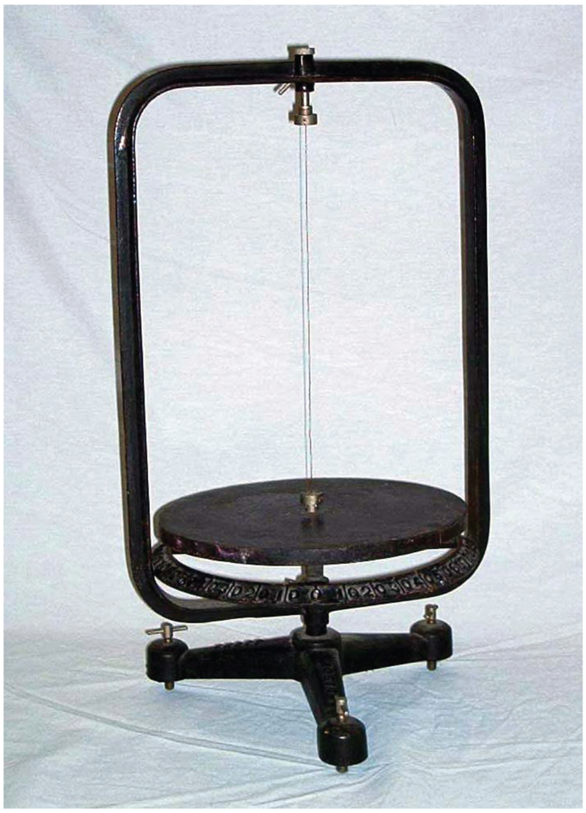
[1]David Reitze, LIGO Collaboration Press Conference, February 11, 2016.

[2]A. Einstein, "Die grundlage der allgemeinen relativitaetstheorie" (The Foundation of General Relativity Theory), Ann. Phys. **354**, 769–822 (1916). English translation by S. N. Bose, https://en.wikisource.org/wiki/The_Foundation_of_the_Generalised_Theory_of_Relativity.

[3]B. P. Abbot *et al*., "Observation of gravitational waves from a binary black hole merger," Phys. Rev. Lett. **116**, 061102 (2016).

[4]See <http://grc.org/programs.aspx?id=12968> for more information on the upcoming GRC.



Torsion Pendulum

The entry about this apparatus in the 1916 catalogue of the L.E. Knott Apparatus Co. of Boston is: "**Improved Sabine's Torsion Pendulum** for determining the moment of torsion of a wire and the moment of inertia of a ring. Two methods of reading torsional vibrations are possible, – by direct observation of consecutive transits of the index past the zero point of the graduated arc; by observing through a telescope the consecutive flashes from the illuminated mirror. The disc is 10½ inches in diameter, and is clamped to the wire by means of a small chuck fixed at its middle point. This disc is then supported from the frame by a similar chuck having the additional features of an adjusting thumb screw and a set-screw. The index dial is cast from metal and has large raised figures. A ring [whose] moment of inertia is to be determined has the same diameter and mass as the disk... $15.60." The apparatus is in regular use at Kenyon College. (Notes and picture by Thomas B. Greenslade, Jr., Kenyon College)