Some Thoughts on Involving Undergraduate Students in GR-Related Research

Thomas W. Baumgarte

Department of Physics, Bowdoin College, Brunswick, ME 04011

Involving undergraduate students in GR-related research can be difficult, and at the same time very rewarding. The difficulties, I would argue, come in more or less three closely related categories, none of which should come as a great surprise: the limited background of typical undergraduate students, the difficulty of finding an appropriate project, and the limited time available for research. By writing about these issues, based on my experience at Bowdoin College, I risk stating the obvious, but perhaps my observations are nevertheless a useful starting-point for discussions. I will also mention another issue that I have sometimes struggled with, namely the fact that students may carry out the research as part of a credit course. The rewards of working with undergraduate students, on the other hand, may be less self-evident, and should definitely be a part of these discussions.

1 Limited background

Carrying out meaningful research in general relativity obviously requires a solid understanding of the subject. A rigorous introduction to general relativity, however, is not very often offered as part of an undergraduate curriculum.

Clearly, the situation is different at different institutions: some places may offer an undergraduate-level introduction to GR, at some universities undergraduates can also take graduate-level courses in GR, while other places may offer a "physics-first" introduction or no course in general relativity at all. The relativity course at Bowdoin, for example, covers special relativity and some concepts of GR, but introduces only very few of the mathematical tools. A typical student interested in becoming involved in GR-related research, then, rarely has an understanding of GR even at the level of the textbook by Schutz.

To make the problem even harder, typical research in GR requires knowledge that exceeds even the material covered in a graduate-level course. Numerical relativity, for example, also requires an understanding of decompositions of Einstein's equations as well as of computational physics and numerical algorithms.

To address this issue I have found it necessary to both offer extra support to students to learn this material, and to limit my expectations.

In terms of offering extra support, I sometimes offer an independent study course on GR. In this course students read a textbook on GR more or less independently, and I meet with them once a week to discuss problems or questions. In the past I have used Schutz's textbook for this course, but Carroll's new book might be an attractive alternative. Offering such a course works better – and is more worth our time – if several students take it simultaneous. I have found it useful to offer such a course during the spring term, to prepare students who start research in the summer.

In terms of limiting expectations, I also believe that it is adequate for undergraduate students to have a more limited understanding of a project than what we would expect from graduate students. For example, when assigning a project on initial data, we would certainly expect a graduate student to be able to derive the constraint equations in the particular decomposition adopted in the project. For an undergraduate student, however, it may be sufficient to have a more qualitative understanding of where the equations come from, as long as they have the mathematical tools to manipulate the equations themselves.

2 Research as a credit course

Typically undergraduate research come in one of two kinds: either they carry out the research as a research project during the summer, in which case they are paid some stipend, or they work on the research during the academic year, in which case they often enroll in an independent study course and get academic credit. At Bowdoin, the research may lead to an honor's project, which entails writing a thesis as well as an oral presentation.

The awkward aspect of this is that as supervisors we have to give academic credit for the students' progress on the research project. Clearly, every research project is very different and – other than completion – it is difficult to formulate well-defined goals or objectives. Unlike in typical lecture courses it is therefore very hard to come up with suitable and objective criteria for assigning a letter grade.

In anticipation of this difficulty I talk about this issue with every research student before they sign up for an independent study. I try to formulate my expectations as clearly as possible – for example regular weekly meetings and updates – and discuss the level of time commitment that I expect. Having such a conversation may also help with some of the time constraint issues that I discuss below.

3 Choosing the right project

Probably the most difficult aspect of involving undergraduates in GR-related research is identifying a suitable project. Such a project has to meet a number of criteria: it must be sufficiently simple and limited in scope, so that a student with very limited background can solve it; it should be interesting, because otherwise it's not worth the effort; but it also shouldn't be too interesting, because otherwise somebody else is likely to do it before the student can finish it. My personal

goal is to have students work on projects that may lead publishable results, even if it is a very short paper in the style of a "Brief Report" in PRD.

There are different types of project that meet the above criteria. My personal favorite type of a project is one that is completely self-contained, so that the student can see it through from the beginning to the end. These projects are hard to come by... As an example, I had one student study spherically symmetric shells of non-interacting particles, and compare criteria that different research groups had used to identify circular orbits for binary black hole systems. Spherical symmetry is probably a very good starting point, but of course there is only a very limited number of interesting problems that can be done in spherical symmetry...

Another possibility, at least in numerical relativity, is to have students use or modify existing codes to explore certain effects. For example, I have had students use a code that models rotating neutron stars to find the maximum allowed mass of differentially rotating neutron stars for different equations of state.

Yet another possibility is to have students study a model problem that perhaps is not even relativistic in nature, but illustrates some aspects of an effect that is also encountered in GR.

4 Time constraints

One great challenge that we face when carrying out research projects with undergraduate students are the time constraints. These constraints come in two different flavors: one is the fact that undergraduates graduate at a certain fixed time, and the other is the fact that undergraduates have to take classes, so that they can only devote a small fraction of their time to research. Both of these aspects are very different from what we might be used to from graduate students. At least advanced graduate students devote all of their time to research, and they do not graduate until the research has come to a reasonable stopping point.

Graduation is a fact of life that we cannot do much about. To make things worse, the last weeks or months before graduation are often filled with many distractions. While we would hope that students focus on their project during that time, tie up loose ends and finish up their thesis, the reality is likely to be quite different. Add to this a more or less severe case of senioritis, and progress may come to a grinding halt.

Even without these adverse effects of impeding graduation, the productivity of undergrads during the academic year can be quite low. This is very understandable, of course, since their prime responsibility is to take classes and do well in them. Taking classes means that there are regular deadlines, for example homework sets, midterms and finals. Research projects rarely come with fixed deadlines, and therefore may easily end up on the "back burner".

The best time to do research with undergrads, then, is the summer. In fact, I usually ask students who would like to work on an honor's thesis with me to spend the summer prior to their senior year working on their thesis project with me. Unfortunately that means that students cannot enroll in an REU program that summer, which could also be a very valuable experience. I instead suggest that they apply for REU programs for the summer before their junior year. The down-side of this plan is that most REU programs prefer rising seniors over rising juniors.

For the future, I am also planning to ask honor's students to spend at least one week of their senior's year spring break at Bowdoin. Luckily Bowdoin College has a two-week spring break, so that this does not rule out a more typical spring break. However, during that time students often have to visit perspective graduate schools as well, which again takes priority over finishing an honor's project.

To help students stay focussed during the academic year it helps to have regularly scheduled meetings – for example once or twice a week – and to discuss in each meeting what should be accomplished by the time of the next meeting. I have also found it useful to tell my students what level of time commitment I expect. Formulating these clear expectations also makes it less awkward to assign a letter grade, as discussed above.

5 Rewards

Having discussed all these problems, challenges, and potential pitfalls of GR-related research with undergrads it may come as a surprise that I find it profoundly rewarding to involve undergrads in my research. For these undergrads this is usually the first exposure to serious research, and they choose to do this because they think it is "cool". Unlike graduate students, many of whom have already made acquaintance with the frustrations of never-ending and possibly irrelevant research projects, undergrads enter a new and exciting world and are therefore extremely motivated.

Whether or not the above holds for every student may depend on the institution. At Bowdoin, the completion of a senior's thesis is not required, so that only the truly interested and motivated students get involved in research. At other institutions where a senior's thesis is required, it may be more of a challenge to find a project for every student, and to motivate every student to bring the project to a meaningful conclusion.

Nevertheless, I believe that working with undergrads provides the opportunity to work with highly motivated, and in many cases also very appreciative students. To further boost the students' motivation I have found it very useful to bring them to conferences. For students the attendance at a conference is very exciting, and learning that there is a whole community that works on related subjects and uses the same language can be an exceptionally motivating experience. The regional relativity meetings provide a very useful forum for this purpose: they are informal, inexpensive, and if students have already completed a sufficiently interesting project they can even give a presentation themselves.

Finally, working with undergrads has led me to work on some small projects that otherwise I probably would not have taken the time for. As it turns out, some of those projects proved to be quite enjoyable to work on. Working on a simple and transparent problem that provides some useful insight can be very satisfying, and may provide a welcome break from the much more complicated and involved projects that we may otherwise be involved in.