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# Searching for Stellar Explosions to Teach the Process of Science

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Research-based science education (RBSE) is an instructional model that integrates scientific research with education by giving introductory-level undergraduate astronomy students an opportunity to do authentic research with real data. Its goals are threefold: (1) to teach that science is a process of discovery, not just a body of knowledge, (2) to improve attitudes towards science and STEM careers, and (3) to develop critical thinking, teamwork, and goal-driven work skills that are important in any career path. The RBSE curriculum currently consists of five authentic research projects in astronomy. Each project uses real astronomical data from professional observatories to investigate authentic research questions for which the answers are not known. In other words, in order to learn science, students are given the opportunity to actually *do* science. The results of RBSE student research have been submitted to scientific databases, presented at professional conferences, and published in refereed journals. In this paper we introduce the RBSE instructional model. To serve as an example, we also describe one of the RBSE research projects wherein students are searching for classical novae in the Andromeda Galaxy (M31). We encourage instructors interested in incorporating the RBSE curriculum into their teaching to learn more at the RBSE websites.

## Introduction

The RBSE method of instruction models the processes of scientific inquiry and exploration used by scientists. It is "research based," integrating *scientific* research with education. It brings the excitement of discovery to classrooms by giving students the opportunity to do science, not just study it through lectures removed from the actual research process. Students participate in research projects, utilizing research-class telescope observations, analyzing data and interpreting their results. Like professional scientists, they work together as collaborators in a cooperative environment. The collaboration method varies depending on the implementation. In general students work in groups on the nova discovery process, with overlap in search regions with other groups to provide a double-blind test. Sometimes that "other group" is from a previous semester, providing a continuous building upon prior students' work.

RBSE is an integration of research and education, teaching science as it is done by scientists. The RBSE curriculum, which is described in the following section, incorporates teaching strategies that model scientific reasoning. These strategies include focusing on a long-term project, engaging in self-organization and reflection, using computers as a tool for data analysis, and using student logs to track progress. RBSE is used in college introductory science courses because, for many students, this may be their last formal exposure to science. It enables students to experience the rewards of research early enough to pursue science as a career, an opportunity that usually comes only to STEM majors, and not before the junior year. Even if students do not pursue STEM degrees, RBSE develops skills that are helpful in any career, such as teamwork and interpretation of information and data to draw a conclusion. And for those who become teachers, it leverages the concept of scientific discovery to a broader audience of learners. The importance of an undergraduate research experience in career selection is well established.[1,2] Undergraduate research participation is a key factor for 90% of students who later decide to pursue physics graduate studies, as compared to 65% of those who plan graduate studies in other fields and 68% of the students who plan to enter directly into the workforce.[3] Efforts similar to RBSE, often referred to as CUREs, have been made in other fields, including geology[4,5] and biology.[6]

Over the last 12 years we have developed and tested the effectiveness of RBSE at six partner institutions, which we call the RBSE-U network. This group included two large "research one" (R1) universities (Indiana University-Bloomington and University of Washington in Seattle), two medium-size teaching universities (University of Alaska Anchorage and Chicago State University), and two community colleges (Pima Community College in Tucson, AZ, and Truckee Meadows Community College in Reno, NV). Student gains in understanding the process of science, changes in attitudes toward science and STEM careers, and gains in critical thinking were assessed with various tools, the results of which will be given in a separate paper.

## The RBSE curriculum

The RBSE curriculum consists of five authentic research projects developed for Astro 101 students. Each project consists of:

1) real scientific data,
2) curricula to teach the necessary data-analysis skills and the relevant science content, and
3) introductory exercises that model the research pedagogy.

Each focuses on a topic accessible to students to which they can make a valuable scientific contribution. Most projects are long term, so that students can build upon the work of prior cohorts. It is emphasized that the RBSE research projects are based upon authentic scientific questions, not static activities. In each case the "answers" are not known and address outstanding problems in astronomical research.

Each project has introductory exercises that teach important research skills, e.g., how to approach a problem like a scientist. These exercises also cover the topical material necessary for the project. For example, the Nova Search project includes several structured activities in which students learn how to search for novae, measure their locations, and precisely determine their brightnesses. We call these "toolbox" activities (instead of "cookbook") because students learn the techniques they will use to complete the project in a manner similar to that advocated by Brown, Collins, and Duguid.[7] Students also learn skills that are valuable in other contexts, e.g., to visually display and interpret data in the form of a graph or chart.

The research projects currently require software to be installed on users' computers. Image-based projects use the ImageJ freeware program, a generic image-processing program developed by the National Institutes of Health. We have written a plugin called Polaris that adds to ImageJ the necessary functions of aperture photometry, astrometry, and timing for a range of FITS data files. Most astronomy data are stored in the FITS data format.[8]

Each project has been designed to match areas in content and pedagogy commonly taught in introductory college astronomy courses. For example, the skills and science content for the Nova Search project include:

**The Nature of Light:**
- The EM spectrum
- Optics and telescopes
- Cameras and CCDs
- Narrowband filters
- Cosmic rays/defects

**The Nature of Stars:**
- Nuclear fusion
- Binary star systems
- Stellar evolution
- Cataclysmic variables
- Accretion

**Tools of Astronomy:**
- Blinking of images
- Aperture photometry
- Astrometry
- Light curves
- Decay rates

Thus, students learn scientific content knowledge in the context of the research project.

## Searching for stellar explosions

For the Nova Search project, images of the Andromeda Galaxy (M31) are obtained regularly (monthly to weekly) with the WIYN 0.9-meter telescope[9] from July through January. Students inspect these images to look for a "nova," an explosive flaring that is caused by a thermonuclear reaction on the surface of a white dwarf star due to mass exchange with a gravitationally bound partner. Neither star is destroyed in the explosion. During the nova the white dwarf will become over a million times brighter than normal, making the normally invisible star visible for a few months to over a year. Students find the novae by "blinking," or rapidly comparing, images taken of the same location on different dates. Novae are therefore found by looking for star-like objects that appear in some images but not all (e.g., Fig. 1). Remarkably, identifying novae is still more effectively done by eye. Computer algorithms are often confused by the complex environment of M31, by differences in image quality due to variable atmospheric conditions (known as "seeing"), and by defects in the image (e.g., cosmic rays that hit the camera).[10]

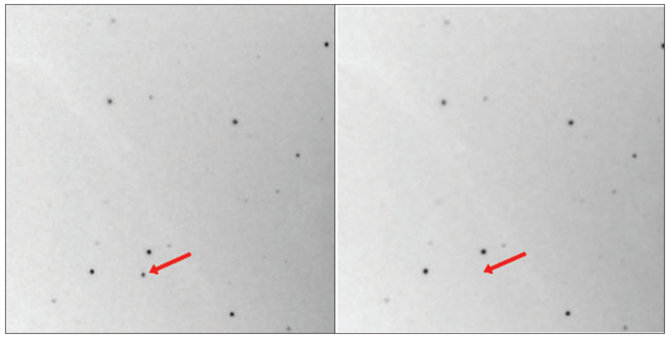

**Fig. 1. Two images taken near the center of the Andromeda Galaxy in August 1995 (left) and July 1997 (right). The images are inverted so the stars look black and the night sky is white. If you look closely, you can see that a nova was erupting in August 1995 in the lower-left corner of the left image. By July 1997 that nova had faded from view.**

Students examine the novae they discover with ImageJ+Polaris. When a nova is found, students measure its location in the galaxy. They then compare its celestial coordinates to previously discovered novae to see if it is a recurrent nova. Students also measure its brightness with a technique called aperture photometry. The photometry is calibrated by using in-field "standard stars" (stars whose brightness is well known, and known to be constant). If a nova remains visible in more than one image, students generate a "light curve" by measuring the nova's brightness in each image and then plotting its brightness over time. They can then fit the light curve with a linear model to measure its rate of decay (e.g., Fig. 2).

Students have investigated a range of questions, such as: Is there a relationship between the distance of a nova from the galactic center and its rate of decay? Do the locations of novae correlate with Chandra[11] x-ray sources? And is there a correlation between peak brightness and rate of decay? There is debate in the literature on these and other questions.[12,13]

## Student gains and discoveries

Over 1000 students have participated in the Nova Search project over the last 14 years. They have inspected 183 images, finding 116 novae in M31 that have been confirmed as real. This is more than any other single effort.[14] The latest student results from this project are presented in Shafter et al.[15]

As part of the program, we also assess students' concep-

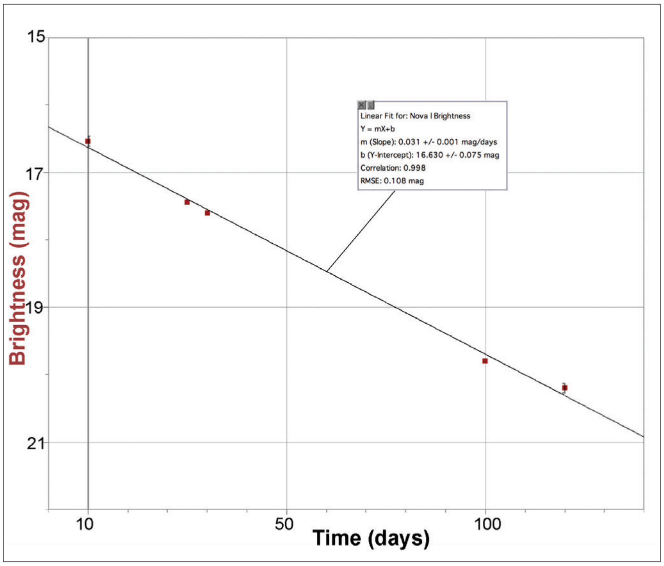


**Fig. 2. Example student-generated "light curve" (a plot of brightness as a function of time) for a nova discovered in M31. Brightness is measured on the magnitude scale, and time is measured in days from the date of discovery. In this example the nova is seen to decay at a rate of 0.031 mag/day, which would classify it as a "moderately fast" nova on the scale proposed by Warner.[16]**

tions of the scientific process and other gains from participating in an authentic scientific research project. The results of those analyses will be presented in a separate paper.

## Conclusions

The learning objectives invoked by many educators often focus on gains in science content knowledge. But authentic science is a process of discovery, not just a body of knowledge. In recent years there have been several calls for teaching to better reflect how science is done.[17] To this end, the RBSE curriculum seeks to engage students in the process of scientific research in an astronomy content-rich context, emphasizing the discovery-oriented work of a scientist. The outcomes examined in this paper reveal that introductory science students, majors and non-majors alike, have the potential to do the work of scientists and contribute meaningful results to science. The extent to which students exhibit learning about the process and practice of science as a result of participating in the curriculum will be presented in a separate analysis.

The RBSE curriculum is free to use by anyone and we welcome instructors who are interested in incorporating the projects in their teaching. Documentation and datasets for the five research projects can be found at these websites:

http://rbseu.uaa.alaska.edu/ (UAA website)
http://www.astro.indiana.edu/catyp/rbseu/ (IUB website)


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