Collaborative Research: Resource of Open Problems for Education (ROPE)

1 Introduction

At the heart of teaching and learning mathematics—and many other disciplines—is a learner's engagement with questions, or problems, which challenge her/him to understand and apply the material s/he is learning. We propose to develop a resource that will provide an online electronic library of innovative, well-tested, and documented problems that instructors and students may use in a wide range of courses and for a wide range of assignment types. This "Resource of Open Problems for Education" (ROPE) will allow searching and browsing to find useful problems; will use information about problem usage and user endorsements to provide a collaborative, "crowd-sourced," vetting process for problems; and will allow users to share collections of problems drawn from the library and groups of such collections. Because it will be an open resource, all institutions and individuals regardless of means will have full access to it, and the community of ROPE users will be able to provide added value to the resource. The goals of ROPE are:

- To be a *free, open-source resource* that will give instructors and students access to an extensive collection of good mathematics problems. The cost of textbooks and supporting materials for courses is increasingly untenable, and ROPE will be not only an expansive resource, but one that does not discriminate on the basis of wealth, and which does not demand advertising or private data for its use.

- To have within this resource a mechanism for users to create *collections of problems, and collections of collections,* that they may use themselves or share with other users. This will allow instructors to create problem sets, quizzes, and collections of these for a course, will allow students to create practice worksheets or other study aides, and, at the other end of the instructional spectrum, will allow authors to define groups of problems that complement their text.

- To develop a *community of users* of these problems, who may contribute problems and related content, may provide feedback on problems, and may share with other users the collections they have created.

With this proposal we seek to develop this core functionality and a sustainable user community for ROPE, which will provide the base from which we may refine and further extend the system.

Figure 1: Mock-up of ROPE search page

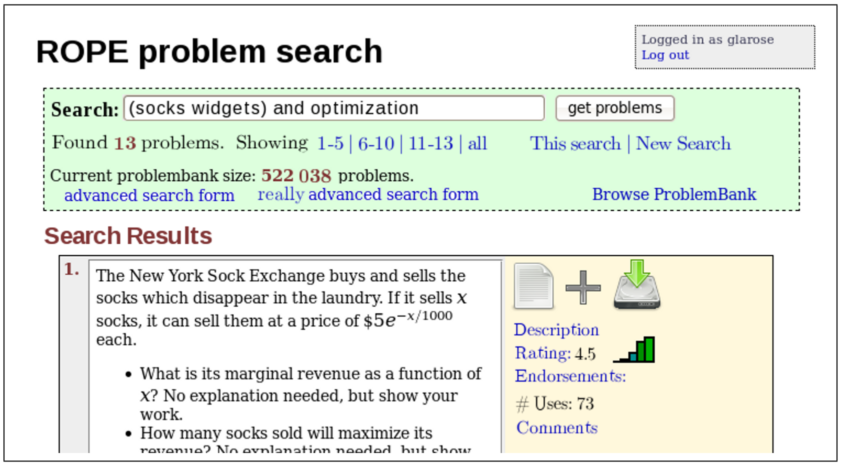

Figure 2: Mock-up of ROPE results page

2 Description

Internet users go to Amazon to search for products to buy, and to Google to find information on the Web. While we do not pretend to be creating a resource with the ubiquity or power of either of those, we do hope to develop ROPE into the place where mathematics teachers and learners go to find problems and inspiration for problems for the courses they are teaching and learning, respectively. We imagine going to the ROPE search page, such as is suggested in Figure 1, and searching for a topic or problem, with the result suggested in Figure 2. These mock-ups illustrate a number of the core features that ROPE will have:

- Users will be able to search on arbitrary keywords, or with Gmail or Google-like tags (e.g., "course:calculus"), and there will be alternate search forms that will allow users to explicitly select specific courses, chapter or section headings, etc. This search will be available to anyone, without requiring that they log in to the site or provide any information. The other user features described below will necessarily require that users establish a username and account in ROPE so that data may be stored for them, but the data collected will be little more than a username and e-mail address.

- Search results will be easily managed, with a view of the problems and easy ways to view the source (e.g., LaTeX) for the problems, add them to Problem Collections owned by the user, and download them as a small file.
- All problems will have useful metadata that describe them, including the background mathematics required for the problem (e.g., calculus and optimization), level of difficulty (e.g., easy, medium, hard), type of problem (e.g., symbolic, numerical, graphical), etc.
- Users will be able to rate problems, endorse them, and leave comments, and these data and other usage data will be used to help organize search results and will be available also to allow other users to evaluate the problems and how they might be used.
- Users will have the ability to build their own problem collections and share them with other users, and to download a full source file (e.g., in LaTeX) for a problem set, other assignment, or even the full list of all problem sets they have created for a course.

In the following we illustrate these core features with three "use cases": how instructors, students and authors might use the resource.

2.1 Authors' Use

An author is writing an open Linear Algebra text, and decides to use ROPE as a source for the problems she includes at the end of each section of her text. She creates a collection in ROPE for her text, and within that collections for each chapter and section. Using ROPE's search tool, she finds problems that she likes for each section of her book and uses the information about the problems to group those in order of difficulty and by type of problem. In selecting the problems she uses both this metadata and the information about other ROPE users' ratings, comments, and the number of uses that the problems have seen. For some sections of her text she finds that the problems available in ROPE do not include all aspects of the material she wants to have covered, and so adds to ROPE some problems to complete the problem sets for those sections. She then makes the problem collections she has created for the text public, and puts links to them and to the problems in them in her text.

2.2 Instructors' Use

An instructor is using a popular calculus textbook from a well-established publisher. His university uses a web homework system that includes problems from that text, so he assigns web homework from that system. In addition, however, he wants to have some written assignments, and to augment the problems available in the textbook he uses ROPE to find related problems that fill in gaps he sees in the textbook's coverage of some of the topics. He creates a personal problem collection in ROPE with all of these problems so that he can easily find them again, and includes them in his assignments by copying the LaTeX code for the problems from ROPE into his LaTeXed homeworks. Each week he gives a quiz to his class, and searches ROPE for problems to modify for his quizzes. For quizzes he copies the LaTeX for the problems and then changes it to give problems that he thinks are at the appropriate level for his students. When searching for problems he is able to use other users' comments and ratings to anticipate where his students may have trouble, and for those problems he finds to be particularly effective he adds some comments and positive ratings. When the semester ends, he shares his problem collection with the instructor who is teaching the course in the following semester so that she can see which problems he used.

2.3 Students' Use

A student is taking the differential equations course at her college, for which her instructor has the usual collection of on-line and written homework, quizzes and exams. Before the exams, the student uses ROPE to assemble some study guides consisting of problems covering the material for which she will be responsible. She uses ROPE's search tool to find problems that cover the right material, and makes a problem collection in ROPE for each study guide. Because these are natively LaTeX documents, she is able easily to download a PDF of each study guide from which to study. As a separate document she creates a version of the study guides that include the answers and solutions to the problems she selected, where they are available. Later she shares her study guide problem collections with friends in the course so that they are able to use them when studying for the final.

2.4 Use Case Observations

As can be seen from these use cases, the power and usefulness of ROPE is rooted in its ability to provide a broad, searchable, library of problems with descriptive data and information about use and usefulness of the problems, and the manner in which it allows users to create collections of these problems for their and others' use and future use. The fact that it is an open resource is a key to this: there is no restriction on who can use these problems, and there is no subscription fee or hurdle preventing its use. It may be noted that as a result of this openness the instructor using problems from ROPE might worry about his students finding the problems or solutions as well. In the face of the ready availability of resources such as Wolfram|Alpha, Yahoo Answers and—even worse—StackOverflow, however, we feel this concern is largely beside the point. In today's world a student can find the solution to any problem we assign (from calculus to graduate topology proofs) on-line, and the availability of ROPE will not affect that. ROPE will provide a resource that can be used to promote and enhance student learning by making accessible a searchable library containing many well-described, effective problems.

3 Context

While there is no resource currently available that provides the functionality and material that will be included in ROPE, there is existing software that will provide a basis for it, and which will inform its development. Three applications that are closely related to the work we seek to do with ROPE are: an existing problem library developed in the mathematics department at the University of Michigan by Gavin LaRose; the Open Problem Library (OPL) used by the WeBWorK [3] online testing and assessment system, for which Gavin LaRose has been a software developer; and Edfinity [6], a commercial website providing content and self-publishing options for educators.

The problem library in use at the University of Michigan currently provides a subset of the features we envision for ROPE: it has an online, searchable interface that allows users at the University to search through over 500 problems drawn from precalculus and calculus homework assignments, quizzes and exams. Problems are described by course, chapter, section, keywords, difficulty, type, original use, year used, author, and general math topic. The experience developing the underlying data structures and interface for this will be of great use in the development of ROPE, and we expect to be able to reuse some portions of its programming code as ROPE is created.

The WeBWorK OPL (Open Problem Library) provides a similar search functionality for over 22,000 problems written for WeBWorK, and is integrated into WeBWorK to allow creation of problem sets from those problems through a library browser interface. But it is, necessarily, strictly a resource of problems for WeBWorK, and therefore does not provide the flexibility and extensibility that we envision for ROPE. It is worth mentioning that the types of problems that we envision for ROPE extend beyond those that are appropriate for WeBWorK. Nonetheless, we do expect that the data structures used in and the experience of the creators of the OPL will provide added insight on the development of ROPE, and its interface with the WeBWorK system will be of particular use as we consider the API for ROPE and how that may allow connections with other systems.

Edfinity is similar in some ways to ROPE (and the WeBWorK OPL), in providing a searchable database of problems with the capability of collecting problems into a problem set—and, in the long-term, an on-line homework delivery system based on WeBWorK. They also allow authors to self-publish problems, with the promise of royalties if the problem is used frequently by other educators. However, it is not an open-source application and does not support the same flexibility in problem collection creation that we envision for ROPE.

In addition to the Michigan problem bank, WeBWorK's OPL, and Edfinity, there are other problem collections that have been developed to serve specific purposes, and we hope to work with the developers and maintainers of those to enhance ROPE and to build connections with them. These include the MathQuest/MathVote question library at Carroll College [1], which includes many questions for use with in-class voting systems; the GoodQuestions project [5], which provides similar types of questions; and Quadbase [4], which is closest in spirit to ROPE but provides more limited options for searching and problem format, and does not support external use or problem sharing, nor the community feedback aspects that we envision for ROPE.

In addition to these specific applications that support some subset of the features of ROPE, there are a growing number of social networking and shopping sites that provide us with interface design principles that will be commonly understood and useful to the users of ROPE. Sites including Facebook, LinkedIn, and Amazon allow users to "like" ideas or objects, providing a powerful and simple feedback mechanism that informs others of the popularity and usefulness of the "liked" item. These sites also allow users to set up collections of objects (like wish lists and shopping carts) that may be used personally or shared with others. Our development of the interface for ROPE will be informed by these sites, and ROPE will adopt these ideas to give users feedback on problems in the library, and to develop problem collections that they may use semester to semester and which they may share with colleagues or with all users of the system.

Finally, we believe that the educational world in which we are working has reached a tipping point that argues strongly for the development of an open resource such as ROPE. There is increasing outcry about the constraints and disadvantages of commercial products and the cost of higher education—which is only compounded by the cost of textbooks and other class resources. The open-source movement continues to demonstrate that it is possible for very good content and programs to be developed collaboratively and openly, and online communities have increased in significance and impact. As more open-content textbooks become available, ROPE will be able to provide a problem resource that complements their problems and work. Programs such as WeBWorK and projects such as Wikipedia demonstrate that free, open development can create products and content that are broadly useful, and which complement and compete effectively with commercial products. And communities such as Project NExT [2] and those connecting instructors using inquiry-based learning have developed into online networks of college faculty who are actively engaged with the use of available resources and technology to improve their teaching (e.g., at the

Legacy of R.L. Moore Conferences [7] and through AIBL [8]).

4 Project Implementation and Timeline

Our timeline to implement ROPE is shown in Figure 3. In summary, we will have an alpha version of the system running after Summer and Fall 2015, to be tested in Spring 2016. In Summer 2016 we will resolve issues that are determined in the alpha test. During the 2016–2017 academic year the system will be in beta-testing. Following Summer 2017 we expect to move the core the system into production.

Each year the PIs will meet twice in person at national meetings. This will allow productive discussions to develop the planning and direction of the project, as well as talks and posters to be presented to initiate its dissemination. In each of the first two years the PIs will meet with the Advisory Group, and with the external evaluator (the latter being paired with the summer meeting). These visits are front-loaded to maximize the formative impact of the discussions we have with them. We will be meeting online with our external evaluator during the course of the project and in person once a year.

All programming and software development will be managed by a hired programming consultant and Gavin LaRose. Problem creation and expansion of the problem database will be managed by Dana Ernst and Spencer Hamblen. They will also recruit alpha and beta testers, who will be paid a small honorarium to contribute problems and provide regular feedback on their use of the system and how it may be improved or how it is working well.

By the end of its beta development stage, we expect that ROPE will have a useful number of problems and the core functionality we require of the system. Essential functions (problem search, collections, and the community of users) will be in place for alpha testing.

Finally, the Math Department at the University of Michigan will be able to provide the required technical support to initially implement and subsequently maintain the computer hardware required for this project. While it is in development and alpha and beta testing, ROPE will be hosted on web servers that are currently maintained in the Department and which have the required capacity to support the project. We discuss ongoing maintenance and sustainability of ROPE as a production service below.

5 Project Personnel

The PIs for the grant are Gavin LaRose, University of Michigan, Dana Ernst, Northern Arizona University and Spencer Hamblen, McDaniel College.

Date	**Personnel**	**Activity**	**Outcome**
Summer 15	PIs, AG	On-site meeting (UM)	Develop design principles, data outline
	PIs, Pr	Development	Programming, database development
	PIs	Meeting (Mathfest)	Assess initial design, revise plan
	PIs, EE	On-line meeting	Frame evaluation, required data
Fall 15	PIs, Pr	Development	Programming for alpha backend, UI
	PIs	User recruitment	Alpha tester recruitment
Jan 16	PIs, EE	Meeting (JMM)	Frame evaluation, data collection
Spring 16	PIs, AG, EE	On-line meeting	Initial program assessment
	PIs, At	Alpha testing	Alpha testing of resource
	PIs, At	Library development	Expansion of library
	PIs, Pr	Programming work	Debugging alpha code
Sum 16	PIs, AG, EE	On-site meeting (NAU)	Evaluation, develop moderation model
	PIs, Pr	Development	Develop beta software
	PIs, AG	On-line meeting	Evaluate beta software
	PIs	User recruitment	Beta tester recruitment
	PIs	Meeting (Mathfest)	Planning, publicity
Fall 16	PIs, Bt	Beta testing	Beta testing of resource
Jan 17	PIs, EE	Meeting (JMM)	Evaluation meeting
	PIs	User Recruitment	Recruit further users
Spr 17	PIs, Bt	Beta testing	Further beta testing of resource
	PIs, EE	Evaluation	Contact users, solicit feedback
Sum 17	PIs	Development	Debugging and interface revision
	PIs	Editorial work	Problem moderation, documentation
	PIs, EE	Meeting (Mathfest)	Evaluation and planning, dissemination
	PIs	User recruitment	Recruit additional users
Fall 17	PI	Development	Development, expansion of library
Jan 18	PIs	Meeting (JMM)	Evaluation of moderation, evaluation and dissemination; future planning
Spr/Sum 18	PIs	Editorial work	Problem moderation, documentation

Figure 3: Project Timeline: personnel notation—PIs = grant PIs; AG = Advisory Group; Pr = contract programmer; EE = External Evaluator; At = Alpha testers; Bt = Beta testers

Gavin LaRose is a lecturer IV and manager of instructional technology in the Department of Mathematics at the University of Michigan. His research interests are in applied mathematics, but he has for the majority of his time post-Ph.D. been primarily focused on undergraduate education. He has been a developer for the WeBWorK open-source homework system and wrote the majority of the testing module for it. In his role in instructional technology at the University of Michigan he has created a wide range of online applications, including data management and tutorial systems. He is the author of the problem library that is currently in use at the University of Michigan, which will serve as the early prototype for ROPE. He has won several teaching awards, including the University of Michigan College of Literature, Sciences and the Arts *Matthews Underclass Teaching Award*, the Michigan MAA Section's teaching award, and the MAA's *Haimo Award for Distinguished College or University Teaching of Mathematics*.

Dana Ernst is currently an Assistant Professor at Northern Arizona University in Flagstaff, AZ. He previously spent four years as an Assistant Professor at Plymouth State University in Plymouth, NH. Ernst's primary research interests are in the combinatorics of Coxeter groups and their associated algebraic structures. His interests also include the scholarship of teaching and learning with a specialization in inquiry-based learning (IBL). He is a Special Projects Coordinator for the Academy of Inquiry-Based Learning and a mentor for several new IBL practitioners. Ernst is also a coauthor for *Math Ed Matters*, which is a monthly column sponsored by the Mathematical Association of America. The column explores topics and current events related to undergraduate mathematics education. Moreover, he serves on the editorial panel for *Math Horizons*. In addition to using free and open-source software (e.g., *Sage*), Ernst is inspired by the recent open-content textbook movement and strongly believes that educators should choose free, open-source, or low cost textbooks when viable alternatives exist. Ernst has been the recipient of several teaching awards, most recently being named the 2009 and the 2011 *Plymouth State University Distinguished Mathematics Professor*, an honor determined by the math majors at Plymouth State University. Moreover, he was a finalist, and PSU's sole nominee, for the statewide *New Hampshire Excellence in Education Award*. Lastly, Ernst received a small internal grant from NAU to fund the initial development of ROPE. Using these funds, he spent the summer of 2013 writing a full sequence of problems for an undergraduate IBL abstract algebra course, as well as a collection of problems to be used for a problem solving course.

Spencer Hamblen is an Associate Professor at McDaniel College in Westminster, MD. His main research interest is Galois representations and deformation theory, but has recently been working in arithmetic dynamics and leading student research on classical arithmetic functions and problems in elementary number theory. His interest in the ways problems shape students' view of mathematics began while a graduate student at Cornell working with the GoodQuestions project. This interest has continued in his current teaching of courses that rely heavily on student problem-solving and other IBL courses.

The Advisory Group for the grant represents constituencies that will have particular interest in ROPE, and includes individuals with a wide range of backgrounds and experience that will allow them to provide insight and advice on the project. **Robert Beezer** is professor of mathematics at the University of Puget Sound. He is an open-content textbook author, having authored a linear algebra textbook, and is an advocate for open-content authoring who has worked with other textbook authors. He is also involved in the *Sage* open-source mathematics software system. **Matt Boelkins** is professor of mathematics at Grand Valley State University and is has developed a free, open-source calculus textbook. He is associate editor of the journal PRIMUS (Problems, Resources, and Issues in Mathematics Undergraduate Studies), which is one of the main journals devoted to the teaching of collegiate mathematics. **Jason Grout** is an assistant professor at Drake University and a leading developer for the open-source math software system *Sage*. In addition, he is active in producing open-source teaching materials for a variety of mathematics courses. **Jeff Holt** is professor of mathematics at the University of Virginia, and is one of the authors and continued developers of the WeBWorK Open Problem Library. **Ben Woodruff** is a faculty member at Brigham Young University–Idaho and an active participant in the IBL instructor community, having produced IBL course materials for several courses including second semester single-variable calculus, Multivariable Calculus, Differential Equations, Linear Algebra, Introductory Statistics, Abstract Algebra, Introduction to Proof, and Topology. All of the members of the advisory group have expressed enthusiasm for the ROPE project and willingness to serve in this capacity.

The project will have an external evaluator, **Doug Ensley**. He is professor of mathematics at Shippensburg University, has been editor of the Mathematical Sciences Digital Library, has written a discrete mathematics textbook, and has been second vice president of the MAA. He has written a library of computer-based material for the teaching and learning of mathematics and has written award-winning Adobe Flash educational materials. He is currently developing mathematics applications for mobile devices.

In addition to these individuals, we will hire a programmer to assist with the coding and database revision that will be done to the University of Michigan codebase in the course of developing ROPE. These revisions will be significant, and the programmer will work in close collaboration with Gavin LaRose to develop a codebase for ROPE which will then be open and easily maintained and extended as appropriate.

6 Sustainability and Editorial Management

There are two significant obstacles to the long-term success of a resource such as ROPE: sustainability of hardware and software, and editorial management of a growing library of resources. While we expect to have to deal with both, ROPE is well-positioned to transcend both of these obstacles.

Hardware and software sustainability—Through its development phases, ROPE will be supported on existing server infrastructure maintained by the University of Michigan Department of Mathematics. As we move to production, ROPE will run on grant-purchased hardware running Linux. This will be installed at the University of Michigan and, as a resource that supplants and extends an application already in use in the Department, will be maintained by Gavin LaRose and the systems staff supporting his department. At the end of the lifespan of that hardware the PIs will explore the requirements for continuing the resource. The cost of this type of infrastructure is low, and we expect that a combination of departmental support, voluntary user contributions, and other external funding will allow continuation of the resource either on dedicated hardware or through some sort of cloud service. Gavin LaRose will be able to provide basic software support and maintenance for ROPE as part of his instructional technology position. We anticipate that within the ROPE community there will be individuals with the technical skills to further develop and help maintain the software, and will create a developer community within the greater ROPE community who are able to improve and expand the capabilities of the system.

Editorial management—As the number of problems in ROPE grows, we expect to manage the quality of the problems in two primary manners. First, we expect that the data model and crowd-sourced problem evaluation and usage data, used in the search result determination, will allow ROPE to provide the better problems in the library preferentially. Thus, we expect that the overall library quality will be in part managed by the filtering that will be built into the problem search capability in ROPE. Second, we expect that the moderation plan developed in the course of the project will include the establishment of an "editorial board" composed of individuals from the ROPE community who will be able to moderate, improve, and correct the problems that are present in the library.

7 Dissemination

Key to the success of ROPE will be its dissemination: for it to be able to reach and help many instructors, they must know of its existence. To successfully ensure that mathematics faculty are aware of ROPE, we will pursue a four-fold dissemination plan: generating a primary user base by soliciting and engaging likely users; publicizing the availability of ROPE to the networks of colleagues available to Ernst, Hamblen and LaRose; publicizing ROPE to the larger community; and communicating with professional organizations and open-source projects to make connections with their members.

To generate a primary user base for ROPE, we will actively solicit alpha and beta testing consultants. These users (about 15 individuals for each of the alpha and beta development phases of the project) will be selected by Ernst, Hamblen, and LaRose (in consultation with the Advisory Group) as people we expect will have interest in ROPE, and whose role with the project is likely to be more than simply searching for problems. We will encourage their participation in rating problems, making comments, and providing problem collections, by offering them a small honorarium for their work. These individuals will provide a base of actively engaged users of ROPE in the critical phases of its development, which will help foster its long-term user base.

The PIs are well-positioned to communicate with a large number of faculty who are likely to be users of ROPE because of their connections with other projects and organizations. All three PIs are Project NExT [2] Fellows, and Gavin LaRose was a member of the Project NExT leadership team from 1997–2012. Project NExT is a professional development program of the MAA that supports new math faculty in all aspects of their professional career, with an emphasis on teaching. There are over 1500 Fellows from all parts of the United States and some surrounding countries and territories, and they are distinguished by their energetic embrace of new ideas and effective teaching strategies. We will publicize ROPE to the Project NExT Fellows, and have good reason to expect that many of them will use it. In addition, the Mathematics Department at the University of Michigan provides a large potential base of users, not only at the University but at other institutions, as well. Each academic year approximately 100 graduate students, post-doctoral, and regular faculty teach in its Introductory Program courses, which currently use the University of Michigan problembank; we will publicize the availability of ROPE to them. The majority of these graduate students and post-docs go on to take other academic positions, and will take their use of ROPE with them to those positions.

To promote awareness of ROPE further, we will disseminate information about it at national mathematics meetings. This dissemination will include presentations in poster and contributed sessions at the MAA's MathFest in the summer and the Joint Mathematics Meetings (JMM) in the winter, which attract essentially all potential users of ROPE. At the JMM we will also rent a booth in the exhibit hall for the meeting to have a demonstration of ROPE. Because the exhibits are a popular attraction of the JMM, we expect this will increase the number of people who are aware of ROPE by several hundred. In addition, we will disseminate fliers about ROPE at the booth and in person at the meetings.

Finally, we will work with professional organizations and the larger open-source communities to promote ROPE. The project personnel are involved with many communities with whom we will make contact, including the MAA, WeBWorK, Sage, and the IBL community, and we will work to develop additional contacts and communication channels with these groups.

8 Evaluation

Evaluation of ROPE will be formative and summative. We expect to get a large amount of significant evaluation feedback from the Advisory Group and Evaluator starting at the beginning of the project—these individuals were chosen because of their interest in and insight into what will make ROPE successful. In particular, we expect this to shape the functionality of the system, its general look and feel, and the way we approach the underlying data structures and programming.

The summative evaluation of the long-term success of the system will be driven in large part by informal discussions with our external evaluator in the course of the first summer of the project, and our in-person meeting with him at the JMM in January, 2016. Much of the data we expect to collect, and analysis that it will allow, will be driven by these discussions.

That said, we expect that the success of ROPE may be measured by a number of quantitative and qualitative outcomes. We would like to know the degree to which it is a useful and usable resource for its user base; how many of the problems and collections in the resource are being used, and how good they are; and how many people are actually using it in a productive manner. It would be nice if we could also demonstrate directly that ROPE has a positive impact on student learning and education, but this is unlikely to be possible.

To measure the first of these, how users see and use ROPE, we have the advantage of the existing problembank at the University of Michigan. We will survey users who have used that and who move on to use ROPE to get a sense of how the new resource meets their expectations and needs. We will also develop surveys for our alpha and beta testers to get similar project data. These surveys will be developed in collaboration with our evaluator, and will aim to measure how good the interface, functionality, and underlying data are, as well as to gather information about how we may improve them.

Evaluating the quality of the problems in ROPE we expect to do in a number of different ways. First will be the data internal to the system: how many people are using the problems in collections, how many of them are endorsed or rated highly, and what comments they draw. We will work with our evaluator to determine what reasonable goals will be for these, or how we should change how we are assessing these data. Second, we will in the course of our alpha and beta testing, and in other contexts as possible, get specific feedback from users of the system to determine how good the problems actually are. We have some faith in the ability of mathematics instructors to evaluate how effective problems are, and will survey users to take advantage of this. We expect to extend this to reach non-alpha and beta testing users by having some randomly selected subset of the users of the system of whom we survey to get their feedback on the quality of the resource.

Finally, we would like ROPE to be a resource that many people use. To evaluate this, we will look at the number of active users (that is, users registered with the site who return some number of times), and how they use it. In particular, we will be interested in seeing how many collections they create, how frequently they return to the site, and whether they are endorsing and rating problems or leaving comments. We will also consider the number of users contributing problems to the site. We will revise our goals for these in consultation with our Evaluator.

9 Broader Impacts

We believe that ROPE will be an easy-to-use, high-quality resource that provides something that teachers and learners of mathematics need: a source of problems to evaluate and promote learning. Its broad impact will stem from its ability to be such a resource for a wide range of users, from students looking for sample problems to study from to mathematics instructors creating entire IBL courses. The PIs have extensive and varied contacts with faculty in a large number of institutions and communities of faculty, including Project NExT, those interested in inquiry-based learning, and open-content authors, which will allow for effective dissemination to those groups most likely to use the resource. In addition, the flexibility and extensibility of its design will mean that ROPE can meet the changing needs of faculty in the future and make connections with other software projects for which a library of open problems will be useful. We therefore expect that ROPE will have broad impact, reaching instructors at all types of colleges and universities who are teaching any standard mathematics course in any of a number of different ways. We further expect that as ROPE develops we will be able to extend it to include other disciplines, though that is not a goal of this proposal.

10 Future Extensions

The goal of this grant proposal is to create a resource that will have the core content and functionality to be broadly useful and therefore provide significant added value to the greater mathematical community. We anticipate that at the completion of this grant we will have accomplished this. There are, however, a number of extensions we hope in the long term to be able to add to the system. These are beyond the scope of the current proposal, but we mention them here to emphasize that we see this project as ongoing and having great potential.

- *Varied Problem Formats*—We expect ROPE to initially support LaTeX and plain text problem formats, and to generate output in LaTeX and PDF formats. In the long run we anticipate being able to broaden this significantly, and hope to allow other formats and manage conversion between them.

- *Well-established, Accessible API*—One of the underlying design goals for ROPE will be to have a clearly defined API that will allow other applications to interact with it in a productive manner. This may, for example, allow an on-line interactive text to dynamically include content from ROPE, or a web homework system to query ROPE for problem data. Developing this type of extensibility will, of course, require significant additional work, but we expect that our initial design will allow this type of generalization.

- *Disciplinary Expansion*—Having an open resource of problems would serve many disciplines beyond mathematics. We would love it if we could work with other science disciplines to see how we could expand that problem resources in ROPE to support their courses as well. We expect the data structures that underlie ROPE will be flexible enough to allow this, and hope in the future to undertake this type of expansion.

11 Prior Support

None of the PIs have had prior NSF support in the past five years.