Collaborative Research: A Comprehensive Pathway for K-Gray Engineering Education

Statement of Need

The education of the engineering workforce has never been more challenging or more important than it is today. Engineering and technology impact almost every aspect of our lives – lengthening and protecting lives, enhancing the quality of life, enabling new modes of communication, and creating wealth and economic growth through innovation, value-added products and services, and enabling infrastructures. Although undergraduate education remains the keystone of the engineering profession, as articulated in NAE's *The Engineer of 2020* report [1], it is clear that the education of our country's 2 million engineers and related professionals neither begins at age 18 nor ends with a university degree. Rather, with the shrinking half-life of engineering knowledge, lifelong learning has become an emblem of the engineering education community. The community has likewise focused considerable attention on K-12 issues, where the roots of the declining engineering societies, funding agencies and engineering colleges, the current role and mission of the engineering education enterprise is truly "K-Gray" — spanning K-12, undergraduate/graduate and professional education. [In this proposal, use of "engineering" refers to engineering, engineering technology, computer science, information technology, and related areas of applied science and applied mathematics.]

Educating the K-Gray engineering community in today's digital world requires straightforward yet flexible access to high-quality educational resources. When NSF's NSDL was launched to facilitate the digital sharing of educational resources for STEM education at all levels, this proposal's partners — *NEEDS* (the National Engineering Education Delivery System) and *TE* (TeachEngineering) — independently answered the call by developing high-quality engineering NSDL collections. With this proposal, we present our unified vision to create and steward the *K-Gray Engineering Pathway*, a premier portal to comprehensive engineering education resources within the greater NSDL. We envision the *K-Gray Engineering Pathway* as the engineering "wing" of the National Science Digital Library that serves resource providers and users from a broad spectrum of constituencies — elementary, middle and high schools; two/four-year undergraduate programs; graduate and professional schools; and lifelong learners.

The proposed *K-Gray Engineering Pathway* builds upon a strong foundation of current and past NSF- and NSDL-supported projects, and enables a critical partnership between *NEEDS* and *TE*. With roots in the Synthesis Coalition [2-4] and digital library development experience since the early 1990s, *NEEDS* now enables more than 3,000 registered users to search, download, and comment on 8,000+ learning objects to aid their learning or teaching. The *TeachEngineering* collection, developed in the past three years, contains 300+ engineering-driven curricula and Living Labs (web portals to real-world engineering systems) for use in K-12 STEM classrooms. The proposed partnership combines *NEEDS*' expertise in higher education and lifelong learning with *TE*'s K-12 expertise and experience to provide engineering resources for the K-Gray continuum. This partnership enables *TE* and *NEEDS* to consolidate technical services, to collectively reach a broader and greater constituency, and to capitalize on each other's strengths. For example, *NEEDS*' pioneering efforts in developing a "tiered" evaluation system for digital library resources will be applied across our collections. Likewise, the *TE* tools and protocols that map curricula to math and science standards of multiple states will greatly assist in the mapping of undergraduate resources to the Accreditation Board for Engineering and Technology (ABET) accreditation criteria.

NEEDS and *TE* are ideally positioned to steward the comprehensive NSDL *K-Gray Engineering Pathway*. By combining, consolidating and improving our collections and technical services, and by partnering with key engineering professional societies — with a collective membership of 700,000+ — we envision a comprehensive and sustainable infrastructure of high-quality, highly-used resources for engineering education.

K-Gray Engineering Pathway Target Audience

Through March 2005, *NEEDS* cataloged 8,000+ learning objects and 3,000 registered users. *TE* has already published 20 K-12 curricular units, containing 111 lessons and 201 hands-on activities, with plans to double

the collection in the next two years. The number of *NEEDS* accesses average 10,000-20,000 per month (with peaks at 40,000). This *K*-*Gray Engineering Pathway* project expands the audience of NSDL users to include students and educators from all levels. The NSDL *K*-*Gray Engineering Pathway* target audience includes:

- Higher education professionals seeking access to ABET-related engineering education resources.
- Engineering students in higher education community colleges, predominantly undergraduate universities and research universities all of whom seek to supplement courses with NSDL resources.
- Engineering professional society partners, including faculty, government and industry members.
- Corporations, engineering professionals, engineering faculty and college students involved in K-12 engineering initiatives that need engaging, standards-based K-12 engineering resources.
- K-12 teachers, university professors, parents, students, professional development groups, summer enrichment programs and service organizations creating communities of learners knowledgeable in the real-world concepts used in engineering and applied sciences.

K-Gray Engineering Pathway Project Goals

Key stewardship goals of the K-Gray Engineering Pathway are to:

Goal 1: Merge *NEEDS* and *TeachEngineering* into a unified *K-Gray Engineering Pathway* with common infrastructure, interoperability between partner collections, recommender systems, archival services and metathesauri to enhance browsing, searching, cataloging and other stewardship functions.

Goal 2: Significantly and sustainably grow the *K*-*Gray Engineering Pathway* by: 1) gathering higher education and professional resources related to cutting-edge research in key areas, 2) creating an *ABET Accreditation Series* for higher education, 3) harvesting K-12 resources from targeted projects (including 26 engineering-related GK-12 awards), 4) leveraging engineering education content and services within existing NSDL collections, and 5) infusing resources that focus on inclusion and diversity in engineering education.

Goal 3: Align the *K*-*Gray Engineering Pathway* curricula with appropriate undergraduate or K-12 educational standards. Use *ABET* accreditation criteria for indexing, evaluating, selecting and reusing undergraduate engineering content, and align *TE* curricula with the K-12 STEM educational standards of all 50 states.

Goal 4: Increase the number of *K*-*Gray Engineering Pathway* content providers and users by: 1) forming partnerships with ABET, American Society for Engineering Education (ASEE) and key disciplinary and women/minority-serving engineering professional societies to reach all engineering educators, industry and K-12 teachers, 2) hosting K-16 and engineering educator user and content provider workshops, and 3) creating an enhanced user interface for content providers to easily submit their own curricula to a quality-controlled prepublication process.

Goal 5: Enhance and implement integrated and interoperable quality control and review protocols for all *K*-*Gray Engineering Pathway* content.

Goal 6: Create a nonprofit strategy and partnership for sustaining the *K-Gray Engineering Pathway*, engaging industry, academe and other nonprofits. Provide a sustainable income stream through value-added educational digital library services to professional societies that enable them to build linkages to the NSDL, and develop an income stream through dissemination services to NSF (and other) engineering education grantees.

K-Gray Engineering Pathway Project Design

Goal 1: Merge *NEEDS* and *TE* into a Unified *K-Gray Engineering Pathway* — *NEEDS*, a digital library for engineering education, pioneered the development of educational digital libraries in the early 1990s with a focus on undergraduate engineering education. Users can search for, download, and comment on learning or teaching resources. *NEEDS* conducts content quality evaluation through a "tiered" evaluation system consisting of a basic metadata-reviewed level, a level with annotations, a community-reviewed level and a

premier level (culminating in the annual *Premier Award* for Excellence in Engineering Education Courseware) [4-6].

NEEDS' capabilities were updated in 2003 to include advanced search and browse, cataloging, user comments and reviews, workspace/portfolio, interoperability, metathesaurus generation and recommender systems. A gender equity sub-collection (in partnership with the Gender and Science Digital Library and MentorNet), and a collection on Women in Information Technology (in partnership with the National Center for Women in Information Technology and the Association for Computing Machinery) were also added. *NEEDS* implemented a strategy to refresh its web portal and metadata with timely engineering content. Monthly themes such as a gender equity collection to coincide with the celebration of the life accomplishments of Anita Borg and African American engineers in honor of Black history month (see Figure 1) were developed.

The *TeachEngineering* digital library, a collection of K-12 engineering curricula, was created to address the critical need for K-12 engineering curricula to be standardized and nationally distributed. The collection went online in January 2005 (see Figure 2), and contains searchable, K-12 engineering curricula aligned with STEM educational standards. *TE* also hosts "Living Labs" — web portals to data and associated curricula for real-world engineering systems. *TE* offers enhanced teaching and learning experiences by providing users with high-quality educational STEM resources focused on engineering applications and curricula, scientific inquiry and pedagogy. The *TE* collection provides opportunities for teacher authorship within the forum of an established, high-quality, web-based publication of teaching resources with common components and a consistent "look and feel."





Fig. 2: TeachEngineering collection home

Create a Common Look and Feel for the K-Gray Engineering Pathway — We propose to merge *NEEDS* and *TE* into a unified *K-Gray* engineering educational digital library, increasing the target audience through a set of complementary partnerships and initiatives, and through optimizing and integrating resources and infrastructures. Users will reach the unified *K-Gray* portal through <u>www.needs.org</u> or

<u>www.teachengineering.com</u>. Search and browse functions from the main website will be performed over the union of metadata of both collections so that collection items can be (re)used across different domains (e.g., K-12 and undergraduate learning). However, the user interface will employ different "branding" and navigational strategies to create tailored presentations optimized for the needs of different target communities; for example, the *NEEDS* logo will be used on pages that service higher and continuing education communities and the *TE* logo will be used for K-12 communities.

Provide Technical Services and Interoperability — We will continue to export the normalized Dublin Core metadata through our OAI (Open Archive Initiative) servers for harvesting by the NSDL Core Integration (CI) initiative. In addition, we will offer a comprehensive and publicly accessible SOAP/WSDL/UDDI web service based on the one already offered by *NEEDS*. Additionally, the richness of the Learning Object Metadata (LOM) will be available to the NSDL, partner collections and professional societies through federated search. To extend the *K-Gray Engineering Pathway*'s reach, we will deploy interoperability mechanisms with new

partner collections and collaborate with the CI team to selectively harvest engineering-related metadata from the NSDL Metadata Repository. This will enable us to extend the NSDL Metadata Repository's usefulness by serving as a new access mechanism for engineering NSDL resources. *K-Gray* will also extend its harvesting and agent-based federated search to interoperate with other NSDL engineering-related collections (e.g., see MOU with the Pollution Prevention Resource Exchange in the *Supplementary Documents*). To facilitate interoperability, we will make our metadata cross-walk tool available for easy importing and exporting of resource definitions. As appropriate, we will draw on *NEEDS*' cross-domain metathesauri research to enable better browsing of resources, improve the precision of user queries and facilitate interoperability between collections.

Expand Recommender Service — We will enhance our recommender services to better guide users to resources of interest through improving our current facilities, now built around a Latent Interest Analysis content-based algorithm that does not require user-rating data [7]. As the quantity of reviewed material increases, we will incorporate collaborative filtering-based algorithms [8-9] using a generative probabilistic model and user rankings to produce a semantic space of user interests.

Promote Collection Stability and Quality Control through Rapid Repair — NEEDS and *TE* generate daily reports on collection integrity; e.g., broken Internet links or unreferenced documents. *K-Gray* will enhance quality control and encourage contributors to more quickly repair known problems and/or automate repairs.

Archive Premier Courseware and Other Learning Resources — *K-Gray* will archive the top level of Premier Courseware and will work with its authors to port to new platforms as the underlying information technology systems evolve. Similarly, we will continue to use generic, proven and established models for the storage and representation of our library to flexibly adopt new technologies without compromising contents.

Unify Personalized User Workspaces — Both *NEEDS* and *TE* provide personal workspaces for registered community members to store links to personalized content and to access personalized recommendations. The *K-Gray Engineering Pathway* will unify the functionality of these spaces to include a unified look and feel, recommender services, and improved printing and formatting.

Upgrade System Infrastructure to Manage Growth — As our *K-Gray Pathway* becomes a premier online publishing site for engineering curricula, system architectures will be upgraded and more user-friendly facilities for managing curricular materials will be developed. In addition, user feedback and review mechanisms will be enhanced. Capability for users to annotate specific sections of documents with comments on the suggested procedures, materials lists, safety procedures, learning outcomes, etc. will be provided. And, new curriculum formatting options will be developed to support a broader range of contributors.

Open Source Software — The K-Gray Engineering Pathway team is committed to the principles of open

source software, and will make our software available to, and invite contributions from, the community. We will also work with the CI team in its strategic directions using FEDORA (Flexible and Extensible Digital Object and Repository Architecture) as middleware for interoperating our web services [10].

Goal 2: Stewardship and Growth of the *K-Gray Engineering Pathway* — A key aspect of library stewardship is active management through acquiring high-demand new resources and systematically deaccessioning (removing from public view) those that are no longer current or are unusable. With advances in engineering and applied science research, a challenge emerges to maintain the

Undergraduate Course Improvement Scenario

Professor Perez is developing an undergraduate course on MEMS and nanotechnology. She wants to add a segment on ethics and social implications to fulfill ABET accreditation criteria. She must find some case studies and other resources, and see what experience other faculty have had in using this material. After finding the needed resources, she downloads her choices and then begins another search — for assessment tools — so she can demonstrate student learning outcomes from this course in her department's outcomes assessment plan. currency of engineering curricula — a need that is becoming more urgent as the gap between employers' needs and the output of educational institutions widens [1, 11-15].

Stewardship of the *K-Gray Engineering Pathway* includes the traditional library roles of "maintaining criteria and mechanisms to identify, select, annotate and generate (rich) metadata for high-quality and relevant digital content as it becomes available" [16]. The lifecycle is supported by planned expansion and cataloging of educational materials that address the advances in science and technology necessary for *K-Gray* engineering education.

The first phase of the NAE's study to identify the future of engineering practice and education, "The Engineer of 2020: Visions of Engineering in the New Century," presents compelling visions for the context in which engineers will practice, and the technical and social challenges they might face — including the need to embrace diversity in the engineering workforce, increasing the roles of engineers in public policy and creating a more adaptive system of engineering education [1]. To be useful for engineering education, the NSDL must provide educational resources on the cutting-edge, as well as in core subjects.

Similarly, significant demand for K-12 engineering curricula has emerged, in spite of the engineering community being poorly versed in authentic K-12 curriculum and pedagogy, and K-12 teachers lacking knowledge of (and often being intimidated by) engineering. To meet this growing demand, numerous engineering-based K-12 curricula have been developed. Until recently, however, there was no vehicle for these curricula to be harvested, distributed and nationally accessed. The *K-Gray Engineering Pathway* proposes to evolve the *TeachEngineering* collection into a national dissemination site for high-quality, engineering-based curricula for K-12 and university educators engaged in K-12 engineering initiatives.

Development and Publishing of K-12 Resources — To position *TE* as a major publishing site for K-12 engineering curricula, we have initiated collaborations with NSF GK-12 engineering grantees, Engineering Research Centers (ERCs), service organizations and science museums to identify, catalog, annotate and review their educational resources for inclusion in the *K-Gray Engineering Pathway*. Collection expansion targets the infusion of educational resources in service learning [17], gender equity and K-12 engineering component resources from science museums (e.g., Chabot Space and Science Center [18], Exploratorium, [19] Lawrence Hall of Science [20-21]) and K-12 digital resources. For example, we are working with several ERCs and GK-12 sites for dissemination of their K-12

educational materials, meeting their need to link to multiple state standards and disseminate to a national audience. Initially, four GK-12 sites, two from states that already have TE standards alignment (CO, MA, NC, OK), and two from other states, will be piloted, permitting us to evaluate and refine the publishing process. We will then expand our efforts to additional engineering-related ERC and GK-12 sites. Further, we will expand TE's Living Labs component through enrichment with activities aligned with emerging technology areas, and by integrating existing rich sources of real-time data with engineering lessons and activities in a studentfriendly web environment. (See letters of commitment from a wide range of supporting institutions in the Supplementary Documents.)

K-12 TeachEngineering Use Scenario

Logan Callahan has volunteered for his company's K-12 engineering program. He's an engineer but not a teacher, so one of his goals is to find curricular components that will spark middle school students' interests in technology and engineering — and encourage girls as well as boys. He initiates his search from the link at his professional society website and readily finds age-appropriate material, some of which, to his delight, is incorporated in a "gender equity" discussion on the site. After downloading a 10lesson middle school unit on navigation and GPS technology, he is off and running. Perfect for his K-12 outreach goals!

ABET Accreditation Series — We will create a new collection to help engineering educators meet ABET challenges through an *ABET Accreditation Series* with criteria for evaluating and selecting materials focused on providing exemplars to engineering higher education. The goal of the *ABET Accreditation Series* is to

disseminate effective practices by building a repository of exemplars and linked digital learning resources. The course improvement scenario above highlights typical problems facing engineering educators who strive to satisfy and surpass ABET educational program objectives and demonstrate outcome-related learning. The ABET-enhanced metadata and exemplar resources will provide faculty with materials for integration into their own teaching/learning environments. Materials might be real-world case-studies that can be used to make or reinforce specific topics, visualizations or demonstrations of specific concepts, problem-solving exercises to fortify learning experiences, raw materials such as pictures and videos for faculty use in classroom or laboratory instruction, or ABET assessment self-study materials on important aspects of a subject. By providing exemplars of current practice and connections to other faculty working on similar issues, this activity will lead to new, broad collaborations that further support engineering education [23]. In partnership with ABET, we will acquire self-study reports containing exemplars. Trained ABET reviewers and professional society members will employ the following process for adding and reviewing materials in the *ABET Accreditation Series*: self-study report nomination; submission; disaggregation of exemplars and application of initial metadata creating an initial collection; triage completing the metadata records and adding annotated reviews; and release and dissemination, making the resource available to engineering educators.

Cutting-Edge Engineering Resources — To meet the needs of engineering education amid the advances in science and technology, to ensure currency in the collection and to address ABET criteria, the *K-Gray Engineering Pathway* will initiate targeted collection development in areas highlighted in the *Engineer 2020* report [1]. This will ensure that the most recent educational materials in bioengineering, biotechnology and biomedical technology and miniaturization — with a focus on resources that address complex and large-scale systems integration, globalization and multi-functional, cross-disciplinary teamwork — are available to engineering educators. See the *Supplementary Documents* section for letters of commitment from partner research centers.

Underrepresented "Majorities" [24] — To promote gender and ethnic minority diversity and equity, the *K*-*Gray Engineering Pathway* will provide a means to include curricular resources such as those generated by the Virtual Development Centers of the Anita Borg Institute of Women and Technology [25-31]. We have already initiated a *Women in IT* series in partnership with the National Center for Women and Information Technology (NCWIT) and the Association of Computing Machinery. We will continue such collaborations with other engineering organizations serving the needs of women and minority communities. We are also committed to accessibility and engaging people with disabilities as developers and users. See the *Supplementary Documents* section for letters of commitment.

Goal 3: Align Curricular Materials with ABET or K-12 Educational Standards — The Education Reform Act changed the learning and teaching environment at the pre-college level. State K-12 educational standards now guide student learning and teachers require relevant, vetted curricular materials to meet these needs. At the college level, led by ABET, improvements to the accreditation process for 680+ engineering departments and programs are providing a renaissance in U.S. engineering education [32-39]. The focus on learning outcomes challenges engineering departments and faculty to design and document classroom learning [33] to satisfy and surpass the ABET criteria. Thus, to be most effective in the engineering education domain, the NSDL must explicitly relate resources in existing collections to ABET criteria and K-12 STEM standards.

ABET Accreditation Series Curriculum Alignment — Collection development guidelines to build and evaluate the *ABET Accreditation Series* will be developed via focus groups with ABET evaluators, disciplinary faculty/administrators responsible for accreditation preparation and ABET staff. As we build the *Series*, we will simultaneously evaluate the nearly 8,000 courseware and other resources existing in our engineering educational digital libraries for relevancy and alignment to ABET criteria. We will also enhance our current metadata and metathesaurus cross-walks to these resources for successful identification via federated searches.

Align K-12 Resources to Appropriate Standards — Most contemporary K-12 curricula are linked to the educational standards of the state in which they were developed, and are typically focused on only one subject area, such as science. But, teachers increasingly need curricula aligned to the standards of their home state.

Toward that end, we will upgrade the *TE* educational standard alignment facilities so that all K-12 curricula can be referenced against key national and all 50 states' STEM educational standards.

Alignment with key STEM standards from 50 states will be accomplished by partnering with two NSDL resources under development. Collaboration between *Align to Achieve* and *JES & Co* will create a single, XML-based format for standards representation which, when combined with a compendium of national standards and key phrases, will create a system for state-to-state standards mapping. The second resource is an automated process for matching curricular resources with educational standards under development at Syracuse University's Center for Natural Language Processing (CNLP). This process will ensure that as many relevant STEM standards as possible are automatically identified for each curricular item. We will work with these standards-alignment groups to integrate their K-12 standards mapping tools into the *K-Gray* system architecture. In a cooperative effort, we are already making our standards-alignment data available to these initiatives for calibration of their automated standards alignment tools. (See letters in *Supporting Documents*.)

Goal 4: Grow the Participation of Content Providers and Users of the K-Gray Engineering Pathway —

Digital libraries that encourage social communities to grow around and interact with their resources will be valued and supported [40-42]. The continuum of participation — from authoring, annotating, adopting, modifying and using digital learning resources — is a critical aspect of the community-building and other services we provide [43]. Our *knowledge ecosystem* considers authors, teachers and learners — developing services for their varying needs, and recognizing that users may play all three of these roles [44-49].

Teacher and Faculty Workshops — Both *TE* and *NEEDS* will provide workshops to expand their user base. *TE* brings experience in designing and conducting effective K-12 teacher workshops while *NEEDS* provides workshops on the use of digital libraries to engineering faculty at professional meeting venues. *K-Gray* will create a new workshop to teach potential contributors how to prepare their own K-12 curricula for publication in *TeachEngineering*. And, a pending NSDL Workshop Track proposal proposes to significantly increase the number of workshops to grow participation of K-16 content providers and users.

Marketing — The marketing plan for the *K-Gray Engineering Pathway* will emphasize the ease of use, quality, and accessibility of learning resources for all target audiences. This plan will deploy existing ASEE resources, as well as advertising and direct marketing through external channels, to reach potential users and contributors.

ASEE has partnered with our *K-Gray Engineering Pathway* team for marketing and dissemination. ASEE reaches 90% of U.S. engineering educators through the society's monthly magazine, *Prism*, and the monthly enewsletter, *Connections*, both of which will feature ads and editorial content about the *K-Gray Engineering Pathway*. Advertisements for the *K-Gray Engineering Pathway* and articles on *K-Gray* users' experiences will also appear in ASEE's monthly K-12 e-newsletter, *Go Engineering*, with a circulation of 35,000 K-12 educators. Print and/or electronic advertising through the National Science Teachers Association and the National Council of Teachers of Mathematics will reach 250,000 K-12 readers during the school year.

Advertisements/announcements in other relevant print and electronic publications — professional engineering societies, the Triangle Coalition, the National Association of State Science and Mathematics Coalitions, the Technology Student Association, and the International Technology Educators Association — will also serve to build awareness of *K*-*Gray* among target audiences by several tens of thousands potential collection users.

K-Gray partner institutions will identify and secure additional sources of support for marketing activities, including contributions from industry, professional societies and foundations. These resources will be used to expand the range and frequency of advertising activities, develop more sophisticated promotional materials, and participate in a greater number and variety of K-Gray educators' professional conferences.

Service Learning — We will disseminate a model for an engineering service-learning technical elective that capitalizes on the *K*-Gray Engineering Pathway. Already piloted at the University of Colorado-Boulder, *K*-12 Outreach Corps is a for-credit engineering technical elective [50], wherein upper division engineering students use *TE* content to teach in two K-12 classes weekly throughout the semester, and also create a new lesson and hands-on activity for publication in the *TE* collection. Using the Outreach Corps as a model, we will partner

with other successful engineering service learning initiatives (see [25-31]) to promote use of and contributions to *K*-*Gray* content (e.g., see letter of commitment from the Anita Borg Institute of Technology).

Goal 5: Implement Enhanced & Integrated Quality Control / Review Protocols for *K-Gray* **Content** — Building on our 10 years experience in creating multi-layered review criteria for engineering education, we will further develop our *K-Gray Engineering Pathway* community through resource ingestion, quality control and reviews, while providing appropriate quality control for our unified collection. This includes enhancing and implementing integrated methods to evaluate the currency of learning resources, and deaccessioning or archiving, as appropriate. We will develop new criteria for ABET alignment with all resources, in addition to creating the specialized *ABET Accreditation Series*, and we will develop a K-12 version of the *Premier Award*.

K-Gray will implement improved quality control standards for the ingestion of new curricula to ensure a level of appropriateness before publishing, and to align with Dublin Core / IEEE LOM educational metadata. This quality control process will employ a required elements rubric and an independent evaluation by experienced K-12 teachers, engineering faculty and engineering content experts, as appropriate. Sample rubrics include:

- Is engineering relevance an integral part of the curricular element?
- Is the pedagogical use and instructional setting well described?
- How well does the lesson or curricular module meet the standards to which it is aligned?
- How well does the assessment evaluate student learning?
- Is the lesson or activity age appropriate?
- Are the materials easy to obtain and readily adaptable?
- How expensive or accessible are the materials?
- Are adequate background and student motivation provided for the educator?

Reviewers for each K-12 curricular element will be identified (though partnerships created during past K-12 engineering initiatives) and trained by the collaborating institutions. They will use the rubrics as a guide to determine whether the lesson/activity pair is accepted, accepted with suggested revisions, or not accepted. As there are a range of institutional types and needs in higher education, rather than using accept/revise/don't accept filters, annotations addressing these rubrics as well as those for the *Premier Award* [5-6] will be used to help users decide whether the resource is appropriate for their setting and educational need.

Goal 6: Create a Nonprofit Strategy and Partnership for *K-Gray Engineering Pathway* **Sustainability** — A significant goal for the *K-Gray Engineering Pathway* is to ensure relevancy, sustainability and growth of the digital engineering education resource when the *Pathway* grant ends in three years. The project team has already embarked in discussions with engineering education leaders in private industry and professional engineering societies to form a collaborative partnership — which may ultimately take the form of creating a nonprofit organization — for long-term support of *K-Gray*. Wayne Johnson, worldwide VP of University Relations at Hewlett Packard, has strongly committed to providing industry leadership and support for creating an entity for *K-Gray* sustainability. (See letter of support in the *Supplemental Documents*.)

In addition to exploring the concept of annual support dues from engineering professional societies, we are evaluating other avenues for securing revenues for value-added services, such as fees for certification and publication of K-16 curricular materials in the *K-Gray Engineering Pathway*, providing dissemination services to NSF (and other) grantees with engineering education missions, and providing interoperability functions to professional society websites so that their members can seamlessly access *K-Gray* and other engineering-related NSDL resources from their society websites. The *K-Gray* Advisory Committee will play a key role in helping the team develop and test various models for sustainability. See the *Strategy for Sustainability* section on page 14 for more details.

Collaboration with Core Integration

The *K*-*Gray Engineering Pathway* provides stewardship, leadership and an organizational center for engineering and technology collections in the NSDL. If funded, we will work with the NSDL CI team to make digital library development and interoperability an increasingly well-defined, off-the-shelf process, ensuring

compatibility and leveraging of existing resources and infrastructures [51-57] and helping to create an open source, component-based set of enabling technologies for digital libraries. As an NSDL Pathways project we will be able to provide richer metadata, beyond the normalized Dublin Core exposed through our OAI servers and currently harvested by the CI. Richer metadata will include IEEE LOM and Dublin Core educational extensions, such as pedagogical intent, reviews and instructional settings. We will be able to offer a comprehensive and publicly accessible SOAP/WSDL/UDDI web service and will deploy interoperability mechanisms with new partner collections, current NSDL engineering-relevant collections and collaborate with the CI team to selectively harvest engineering-related metadata from the NSDL Metadata Repository. We intend to make our metadata cross-walk tools available to the CI for easy importing and exporting of resource definitions, including our *NEEDS* cross-domain metathesauri research to enable better browsing of resources, increase the effectiveness of user queries and facilitate interoperability between collections. We will also work with the CI team in its strategic directions using the open-source FEDORA (Flexible and Extensible Digital Object and Repository Architecture) as middleware for interoperating our searching, harvesting, cataloging, metadata format conversion, and reviewing web services [10, 58-59].

K-Gray Engineering Pathway Key Staff and Management Plan

The proposed project is a collaboration of the *NEEDS* and *TE* teams. The leadership team of highly-qualified PI, co-PIs and senior personnel has a long history of working together on projects associated with educational digital libraries, human-centered computing and instructional technology.

Clear lines of responsibility have been developed (see Table 1). In addition to overall project responsibility, PI Agogino will oversee the technology infrastructure and evaluation. Co-PI Sullivan will be responsible for coordination of the K-12 components and creation of the sustainability plan. Co-PI Tront will lead the development of the *ABET Accreditation Series* and coordinate the higher education review processes. Co-PIs Cyr, Mooney and Ybarra will direct the incorporation of K-12 educational STEM standards, Living Labs, and ingest ERC and GK-12 engineering content, respectively.

Each project team will hold weekly meetings (via tele- or online-conferencing) to update and refine the work, as well as populate a collaborative website. Monthly, all-team joint meetings will document progress and track ongoing tasks. The *K*-*Gray Engineering Pathway* Advisory Committee will meet annually.

Name	Affiliation	Project Responsibilities
Alice Agogino	PI: Roscoe and Elizabeth Hughes Professor of Mechanical Engineering, University of California-Berkeley	 Pathway Design and Leadership NEEDS Project Leader Pathway Sustainability Plan and Execution Pathway Evaluation Engineering 2020 Collection Development
Jacquelyn Sullivan	Co-PI: Director K-12 Engineering, co- Director ITL Program, College of Engineering and Applied Science, University of Colorado at Boulder	 Pathway Design and Leadership TeachEngineering Project Leader Pathway Sustainability Plan and Execution Pathway Evaluation, K-12 QA/QC Processes K-12 Engineering Content Harvesting
Martha Cyr	Co-PI: Director, K-12 Outreach, Worcester Polytechnic Institute	 K-12 Standards Correlation Leader K-12 Engineering Content Harvesting Curriculum Certification
Michael Mooney	Co-PI: Associate Professor, Civil Engineering, Colorado School of Mines	Living Laboratories LeaderK-12 Engineering Content Harvesting
Joseph Tront	Co-PI: Professor, Electrical and Computer Engineering, Virginia Polytechnic Institute and State University	 ABET Accreditation Series Development Higher Ed QA/QC Review & Premier Award Liaison to Engineering Professional Societies Advisory Board Coordination
Gary Ybarra	Co-PI: Professor, Electrical and	Curriculum Certification

Fable 1. Responsibilities for	the K-Gray	Engineering	Pathway key staff.
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	Computer Engineering, Duke University	 Collections Site Testing K-12 Engineering Content Harvesting
René Reitsma	Senior Personnel: Associate Professor, Accounting, Finance. and Information. Management, Oregon State University	 Systems Design and Development Core Integration Coordination User Interface Integration
Eric Iversen	Senior Personnel: Manager for Outreach, American Society for Engineering Ed.	<i>Pathway</i> Marketing and DistributionFaculty Workshop Dissemination
Nancy Van House	Senior Personnel: Professor, School of Information Management & Systems, University of California-Berkeley	 Evaluation Consultant Supervise Interviewers, User Studies, UI
Malinda Zarske	Senior Personnel: K-12 Engineering Curriculum Coord., CU-Boulder, Former K-12 Science and Math Teacher	 <i>TE</i> Curriculum Integration Teacher Workshop Design Curriculum Certification
Bonniejean Boettcher	Senior Personnel: Outreach Project Manager, Worcester Polytechnic Inst.	• TE Curriculum Integration

Qualifications and Results from Prior NSF Awards

Alice Agogino, PI, served as PI and director of the Synthesis Engineering Education Coalition. Also served as associate dean in the College of Engineering, responsible for the Center for Underrepresented Engineering Students, and as PI on several projects targeting increasing and retaining women and underrepresented minority students in engineering. Agogino served as PI for the four-year *NEEDS* Action Agenda grant (EEC 9872570, \$880K, 9/1/98-8/31/03) and two, one-year grants to extend *NEEDS* to other STEM disciplines (IIS 9817406 for \$200K and IIS 9980116 for \$400K). This work provided the foundation for serving as PI for the SMETE.ORG educational digital library (DUE 0085878, \$400K, 8/15/00-7/31/03 and DUE 0127580, \$1M, 10/1/01-9/30/03); and "Developing a Learner-Centered Metathesaurus for Science, Mathematics, Engineering and Technology Education" (DUE 0121743, \$86K, 10/1/01-9/30/03). She has received several subcontracts to provide services to NSDL projects, including the NSDL Collaboration Finder, and in partnership with Exploratorium Online, Chemistry Digital Library, MERLOT and LON-CAPA. See references [2-3, 60-68] for resulting publications.

Jacquelyn Sullivan, co-PI, is PI for NSDL's *TeachEngineering* digital library — a searchable collection of web-enabled, inquiry-based K-12 STEM curricula that went online in January 2005 (DUE 0226322; DUE 0341676 and DUE 0325492, \$991K, 01/01/03-12/31/05, Collaborative Research: *TeachEngineering* — Hands-On Resources for K-12). See results at www.TeachEngineering.com. As PI for an NSF GK-12 engineering grant (DGE 0338326, \$1.9M, 01/01/04-12/31/08, Track 2 GK-12: Inspiring and Building Tomorrow's Workforce: A Grades 3-12 Engineering Continuum), she initiated the *Technology and Engineering to Advance Math and Science* continuum with seven high-needs schools. As PI of the initial GK-12 engineering grant (DGE 9979567 and DGE 9979567, \$1.3M, 9/01/99-8/31/04, Creating an Integrated Engineering and Technology Education Continuum), she explored innovative ways to *use engineering as the vehicle to integrate hands-on science and math* instruction. Created and classroom-tested 60% of the initial *TeachEngineering* curricular contents. See references [50, 69-87] for resulting publications.

Martha Cyr, co-PI, served as PI or co-PI on 29 K-12 engineering, math and science grants for students and teachers. Served as PI on two NSF GK-12 engineering and computer science grants (DGE 9979593, \$885K, 10/15/99-12/31/02, GK-12 Engineering Fellows: A K-12 Resource for Integrating Engineering, Math and Science; and DGE 0230840, \$1.5M, 06/01/03-05/31/06, GK-12: Tufts Engineering the Next Steps). Also co-PI to create the *TeachEngineering* digital library. See references [69, 88-96] for resulting publications.

Michael Mooney, co-PI, served as PI or co-PI on five NSF-funded K-12, undergraduate, graduate or digital library grants in the past five years, including PI for two NSF GK-12 engineering grants (DUE 9950660, \$75K, 7/01/99-6/31/01, Adventure Engineering: A Creativity-Based and Design-Centered Approach to Introductory Level Undergraduate and Secondary School Education; and DGE 0086457, \$1.1M, 3/1/01-8/30/05, GK-12 Engineering Fellows: Adventure Engineering: An Inquiry Learning, Design-Driven Approach

to Middle Grade Science and Mathematics Education). See results at <u>www.AdventureEngineering.org</u>. Also co-PI to create the *TeachEngineering* digital library See references [69, 97-106] for resulting publications.

Joseph Tront, co-PI, served as PI for "A Community to Develop Materials for an Engineering Learning Environment" grant (DUE 0127426, \$460K, 3/1/02-8/31/05), resulting in the development of digital learning resources that support undergraduate engineering courses. Also co-PI for the nine-university SUCCEED Engineering Education coalition [107] (EEC 9727411 and EEC 9109853, \$23.3M, 3/15/92-8/31/03), serving as director of the Technology-Based Curriculum Delivery Center. See references [108-117] for resulting publications and www.ee.vt.edu/~jgtront/CDMELE/ for results.

Gary Ybarra, co-PI, PI on 12 K-12 engineering grants in last six years totaling \$8M, including an NSF Math Science Partnership award (HER 0227035, \$5.3M, 10/1/02-9/30/07, TASC: Teachers and Scientists Collaborating) to narrow achievement gaps and improve the quality of science teaching. Also significant contributor to create the *TeachEngineering* digital library. See references [69, 118] for resulting publications.

René Reitsma, senior personnel, responsible for systems infrastructure and interface development, led the systems design and development for the NSDL *TeachEngineering* digital library. Is a highly experienced information management system project leader, with numerous engineering information systems in production nationwide. See references [69-70] for resulting publications.

Eric Iversen, senior personnel, led the ASEE promotion of the NSDL *TeachEngineering* collection to teachers and faculty nationwide via websites, press releases, publications and conference workshops. He represents ASEE in exchanges with Members of Congress and their staffs, corporate and society executives, and members of the engineering academic community.

Nancy Van House, senior personnel, will serve as an evaluation consultant to our development and implementation at *K-Gray* project onset. She is an expert in digital libraries and their evaluation, and a specialist in knowledge and practice communities. Her research focuses on user-centered approaches to the design and evaluation of information technology, and the interplay between the social and technology [119-120].

K-Gray Engineering Pathway Timeline

Goals / Major Tasks	Year 1	Year 2	Year 3
1. Merge NEEDS & TE	Interop metadata, design UI, dev. integration plan	Implement UI; web portal; merge initial services	Merge all shared services
2. Stewardship and Growth of the <i>K-Gray</i> <i>Engineering Pathway</i> (harvest content / resources, deaccession)	Gap analysis; dev. 30 ABET exemplars; <i>Engineer 2020</i> ingestion; deaccessioning; increase <i>TE</i> content by 50%	Add 20 ABET exemplars; ingest contents: <i>Engineer</i> 2020; GK-12, ERC, etc.; develop two K-12 Living Labs; increase <i>TE</i> content by 25%	Complete and test ABET Series and Living Labs; <i>Engineer 2020</i> targeted ingestion; host 3 ABET series workshops; increase <i>TE</i> content by 25%.
3. Align Curricular Materials with Appropriate ABET or K-12 Standards	K-12 standards database and map alignment; ABET metathesaurus and indexing	25% of ABET-aligned metadata; K-12 standards process verification and integrate mapping tool	100% of ABET-aligned metadata; integrate K-12 state standards correlation; K-12 STEM standards for all 50 states
4. Grow Participation	Develop marketing plan; professional society MOUs; usage workshops	Implement marketing plan and MOUs; enhance GUI for content providers; usage workshops	Analyze results from marketing; expand MOUs; usage workshops

Table 2. Proposed high-level tasks for the *K-Gray Engineering Pathway* development.

5. Develop and Implement Quality Control / Review	Unify procedure for tiered reviews of content; develop criteria for K-12 <i>TE Premier</i> <i>Award</i> ; rapid repair tools	Implement unified reviews; double number of reviews; award NEEDS Premier Award; advertise TE Premier Award	Double number of reviews; conduct inaugural <i>TE</i> <i>Premier Award;</i> make <i>NEEDS Premier Award</i>
6. Create a Nonprofit Strategy & Partnership for Sustainability	Explore models for sustainability; conduct market research; design portal prototypes	Create business strategy; develop MOUs; pilot web services professional society portal.	Implement business plan components
Core Integration	Formalize CI agreement; expose metadata; ingest selective CI repository metadata	Expose richer metadata with educational extensions	Interoperate additional services with CI.
Dissemination	Awareness and promotion; user studies; usage workshops	Mass marketing; PR; usage workshops	Professional society usage workshops
K-Gray Engineering Pathway Evaluation	Evaluation plan; NSDL- wide evaluation; form/hold Advisory Committee meeting	Selected evaluation tasks; NSDL-wide evaluation; Advisory Comm. meeting.	Selected evaluation tasks; summative report; NSDL- wide evaluation; Advisory Committee meeting

K-Gray Engineering Pathway Dissemination

The dissemination plan complements the awareness-building emphasis of marketing by increasing technical understanding of the *K-Gray Engineering Pathway* content among target audiences. The plan revolves around the following themes: Year 1 "Awareness and User Studies," Year 2 "Marketing and Public Relations" and Year 3 "How to Use and Creating a Sustainable Entity." Dissemination activities include: e-mail delivered through project and collaborating institutions networks, electronic materials deployed on websites offering related educational materials, and in-person presentations at conference technical sessions and workshops, with each phase designed to provide audiences with greater command of *K-Gray* resources and applications.

Tailored messages will introduce *K-Gray* materials to education and professional target audiences. For example, messages for K-12 audiences will emphasize conformity to state standards of learning, while messages for higher education audiences will emphasize features such as the currency of educational resources. Channels of direct distribution include professional and educational society membership networks via e-mails, electronic newsletter items and other communication avenues.

In the next dissemination phase, we will place links and substantive materials detailing *K*-*Gray* resources on websites that already convey engineering education-related materials to target audiences. For example, the National Science Teachers Association's website offers a "Teachers' Grab Bag" that details abundant resources relevant to them. Likewise, integrating *K*-*Gray* links and content to professional society websites will establish understanding and promote use of engineering education resources among target audiences.

In the culminating dissemination phase, we will make presentations at annual meetings of professional societies, reaching department heads and deans. Higher education faculty will be reached through sessions, panels and papers at professional society conferences.

K-Gray will also develop and present a fee-based workshop describing the benefits of using the *ABET Accreditation Series* to prepare departments for ABET review. We will develop training materials describing the *K-Gray Engineering Pathway* resources for ABET inclusion in their annual reviewer training workshops. To reach a broad audience, professional society partners will include pointers to the *K-Gray*'s resources in their educational advertising materials. Finally, the team will publish its results in journals, and make presentations at conferences and NSDL-related programs.

K-Gray Engineering Pathway Evaluation

Our overall goal is the establishment and effective stewardship of an NSDL *K-Gray Engineering Pathway*. We intend to develop a thriving community of educators and learners actively engaged in the full lifecycle of *K-Gray* resources, from creation to curation, dissemination and use [119-120]. Nancy Van House, an expert in digital libraries and their evaluation, will serve as our evaluation development and implementation consultant.

Evaluation Plan — Key elements of the evaluation plan include: 1) a community-based needs analysis, 2) definition and collection of usage metrics (e.g., how educators use materials in their classes), and 3) mid-term (formative) and final evaluations. To receive ongoing formative usability and accessibility evaluations, we will expand our current lead user groups to include new partners such as students, faculty, authors and reviewers associated with ABET, professional societies, nonprofits and partner collections.

Performance and User Metrics — We intend to build upon the work of NSDL's *Educational Impact and Evaluation Standing Committee* and *Policy Committee* [51], regarding standard user logs, user demographics, learning resources subject areas, learning resources types and other statistics [121-122]. To perform user evaluations, we will draw upon prior studies, and methods and instruments used by *NEEDS*, providing a useful benchmark against which to measure progress towards current objectives. To better understand user needs, specific quantitative goals will be developed through discussions with partner communities. We will expand performance monitoring applications to automatically report access and performance measures of the system's infrastructure. As an intermediary and service provider, the *K-Gray Engineering Pathway* will provide usage data to partner organizations and individual authors. Our current infrastructure is instrumented to enable our collections, in accordance with our privacy policies, to track usage of a number of key metrics (downloads, queries, federated search queries, "successful" recommendations, etc.). Working with the NSDL leadership, we will unify usage and performance metrics, and produce quarterly evaluation reports for partner collections, professional societies and authors. In this way, evaluation of the *K-Gray Engineering Pathway* and partner collections will contribute to the overall evaluation of the NSDL.

Quantitative Evaluation — As a result of the *K*-*Gray Engineering Pathway* collaboration, we expect rapid growth of the *TE* and *NEEDS* collections. Measures of growth include the number of curricular reviews and annotations filed by users, the amount of time users spend searching and navigating the various collections, the complexity and lengths of the paths they follow while searching, the private user space contents and the number of hits that a query for the *K*-*Gray Pathway* returns in generic search engines (e.g., Google, Yahoo). We will monitor these and other measures, and include the results in our formative evaluations. The following target objectives are proposed as a starting point for increased impact of the NSDL program:

- We plan to add ~10 complete, multi-week K-12 curricular units in each of the project years.
- With the addition of the state STEM standard correlation tools, each K-12 curricular item will become referenced with each state, thereby vastly increasing the reach of the collections.
- The new standard correlations should support broader teacher use. Through documenting user location records, our target is that K-12 educators from at least 30 states use the collection by the end of Year 3.
- Develop higher education collection for coverage of Engineer 2020 topics and core engineering disciplines.
- Align all NEEDS metadata with ABET criteria.
- Increase *NEEDS/TE* usage by 50% each year for three years.
- Double the number of reviews and reviewers of learning objects each year.
- Increase the number of accesses to partner portals from *K*-*Gray* by 50% each year.
- Increase the number of accesses to the NSDL main portal from NEEDS/TE by 30% each year.

Qualitative Evaluation — Although quantitative metrics provide good measures for assessing increased use of the *K-Gray*'s resources, they measure neither the quality of the experience nor how the resources are used. Mining server log data provides a better understanding of how much time a user spends with resources, and

how resources are accessed. These in-depth metrics will be cross-referenced with questionnaires, interviews and observations from user focus groups and registered users.

Advisory Committee — To guide the project in building a sustainable *K-Gray Engineering Pathway*, the project will convene an Advisory Committee co-chaired by John Prados and Barbara Waugh. Working with NSF and the project team, they will identify committee members from professional societies, the digital library community, higher education and K-12 communities and industry.

John Prados served as president of ABET (1991-92), senior education associate in the NSF Engineering Directorate (1994-97) and was founding editor-in-chief of the *Journal of Engineering Education*. He also served as vice president of the University of Tennessee, where he received a Ph.D. in chemical engineering [32-39].

Barbara Waugh is a director for strategy in HP's University Relations and will work with Wayne Johnson, vice president for worldwide University Relations, on behalf of *K-Gray* sustainability. She developed HP's breakthrough programs for women and minority recruiting and co-founded HP's Sustainability Network and e-inclusion.

K-Gray Engineering Pathway Strategy for Sustainability

Conceived as a loose federation of digital libraries that grew from research grants, NSDL faces daunting, longterm sustainability challenges. In addition, any models for sustaining the individual NSDL libraries must be sensitive to the libraries' values, goals and mission [123]. **Our goal is to make the** *K*-*Gray Engineering Pathway* an endeavor that operates as a financially-independent, nonprofit organization by late 2008. We intend to examine and build upon past successful approaches, combining elements of various models to develop a portfolio of support for long-term sustainability. To secure corporate sponsorship and support for this nonprofit, we have begun collaboration with HP's University Relations; see the *Supplementary Documents* section for a letter expressing HP's commitment to leading our *K*-*Gray* sustainability initiative.

Expanding the Business Case — MBA students at OSU have developed an integrated business plan for sustainability of the K-12 component of *K-Gray*. The plan forecasts that with corporate, engineering professional society and modest private support, coupled with for-fee certification of ~500 learning objects yearly, the operation can become financially sustainable. Under this plan, access and use of K-12 curricula for noncommercial purposes would remain free of charge.

Leveraging of Research and Consulting Services — Both NEEDS and its technology infrastructure arm, SMETE.ORG, have achieved success in sustaining a limited number of program elements. We will build upon and improve these strategies to sustain the *K*-Gray Engineering Pathway. Current models are based around a portfolio of support; in the case of NEEDS, initial development was funded through NSF, with matching funds and equipment grants provided by industry (Apple, Autodesk, DEC, IBM, John Wiley & Sons, and Sun Microsystems). In addition, the NEEDS-sponsored Premier Award competition is industry-supported (John Wiley & Sons, Autodesk, MathWorks and Microsoft Research).

Both leveraging of research funds and providing consulting services have contributed towards sustaining SMETE.ORG. Such synergy between research and production systems has enabled the infrastructure behind the *K-Gray Engineering Pathway* to implement, test and deploy new research in digital libraries (e.g., metathesaurus work and wireless access to educational digital libraries. See more detail on our industry/academe/nonprofit workshop on "Learning in the Palm of Your Hand" at SMETE.ORG [124]). The consulting services model leverages existing technologies to assist new and existing collections in providing services to their users (e.g., search infrastructure for the Exploratorium Online [125] and Chemistry Digital Library), and developing the NSDL Collaboration Finder as a service to the NSDL program [126-131].

Relationships with Professional Societies — One key element in *K-Gray Pathway* sustainability will be our relationship with professional societies. Engineering societies have a rich history of publishing journals, hosting conferences and providing access to cutting-edge research via conference proceedings. In most societies, the infrastructure for access to research material has nominally kept pace with advances in technology (e.g., web-based access to abstracts and full-text of journals). However, it is challenging to gain

access to educational resources produced by these societies or through their publications because their metadata are not available for harvesting or interoperability with external sources, including the NSDL. K-Gray will collaborate with professional society partners to identify, integrate and deploy existing technology services through their websites and portals. In Year 1, K-Gray will conduct needs analysis focus groups to define requirements for each professional society partner (see the Supplementary Documents section for letters of commitment from professional society partners). Based on preliminary discussions, we expect that an important service will be to link the engineering professional societies to the NSDL by providing interoperable educational resources and value-added services. These technologies, which will be tightly integrated into the existing professional society websites and/or portals, will enable professional societies to better serve their members, make supporting the service a regular part of their operations (for sustainability), and link their sites to K-Gray and NSDL. During Year 2, we will work with ASME and ACM to develop two "proof of concept" models, providing each with digital library services at their existing portals. In Year 3, we will extend our partnerships with other professional societies to develop a business plan to implement value-added services and linkages to improve the accessibility and interoperability of their educational resources. Such relationships make possible a potential "fee-for-service" model that might enable sustainability of some of the aspects of the *K*-*Grav* resource (such as cataloging to ensure a current collection).

Relationships with Research Centers — Likewise, engineering and technology research centers designate funding to support their education missions. In the case of NSF-funded research centers, grantees are required to develop and make research-based education materials available. The *K-Gray* collections provide an ideal infrastructure for research centers to publish their educational materials, ensuring viable, long-term access to the materials and having the type of educational impact envisioned by NSF's education/outreach requirements.

Fee for Service — Similar to the Public Library of Science author fees, our sustainability model may charge research centers or professional societies a fee to catalog, store and manage their educational resources [132-133]. Similarly, collections of digital learning resources for professional societies could be maintained and expanded through fee-for-service activities. These two areas will be thoroughly evaluated during the project, with business leadership provided by Hewlett Packard. While large-enough output or high-enough contribution fees could sustain a *K-Gray* maintenance operation, other funding sources or new research innovation funding would be required to upgrade and enhance the infrastructure every two to four years.

Conclusion

The collaborative partners of the proposed *K*-*Gray Engineering Pathway* are excited about the potential for creating the "engineering wing" of the National Science Digital Library. The *K*-*Gray Engineering Pathway* is designed to have broad impact, promote quality in educational resources and practice, and provide value-added services to professional societies and the engineering community. *K*-*Gray* provides stewardship, leadership and an organizational center for engineering research centers and the ABET accrediting agency makes the NSDL vision for developing collections and services relevant to professional societies come alive. And, professional society and industry partnerships provide the basis for long-term *K*-*Gray* sustainability.

Letters of Commitment — See the *Supplementary Documents* section for *letters of support and commitment* for significant collaborative arrangements with a wide range of partners.