Peer-Review of Digital Educational Resources—A Rigorous Review Process Developed by the Climate Literacy and Energy Awareness Network (CLEAN)

Anne U. Gold,[1,a] Tamara Shapiro Ledley,[2] Susan M. Buhr,[1] Sean Fox,[3] Mark McCaffrey,[4] Frank Niepold,[5] Cathy Manduca,[3] and Susan E. Lynds[1]

ABSTRACT

Educators seek to develop 21st century skills in the classroom by incorporating educational materials other than textbooks into their lessons, such as digitally available activities, videos, and visualizations. A problem that educators face is that no review process similar to the formal adoption processes used for K–12 textbooks or the college-textbook review process exists for these types of online educational resources. However, educators need authoritative high-quality digital teaching materials. The scientific journal peer-review system offers a well-established model to adapt to the requirements of a peer review of educational materials. In this paper, we review ten review processes developed to evaluate digital geoscience educational resources and focus in detail on a rigorous iterative peer-review process recently developed by the Climate Literacy and Energy Awareness Network (CLEAN) project. This process builds upon existing efforts and emphasizes the "curation" of a digital collection that addresses the Essential Principles of Climate Literacy and the Energy Literacy Principles. Providing educators with thoroughly reviewed educational materials is especially important for fast changing, societally important, and sensitive areas such as climate and energy science. © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/12-324.1]

Key words: digital library, digital collection, peer-review process, climate literacy essential principles, energy literacy principles, educational resources, climate education, energy education

INTRODUCTION

The peer-review process for scientific journals is well established. In contrast, review of educational material is not as formally developed. For example, only half of all U.S. states follow a formal adoption process for K–12 textbooks (Phillips, 2011). The problem is particularly acute for digital educational materials such as online lesson plans and videos, where only a few U.S. states have implemented a system to review these materials. However, the need for authoritative and effective digital educational materials is increasing, as educators seek to teach 21st-century skills (Borgman et al., 2008), expose students to new media, introduce variety into the instructional approach, and include the latest scientific findings in lessons.

The transition from printed educational materials to new media and cyberlearning poses numerous challenges to educators, some of which apply more readily to K–12 educators than to college faculty: First, educators may lack knowledge and training in how to find, use, and adopt digital materials (Hanson and Carlson, 2005; McMartin et al., 2008; Mervis, 2009a). Second, the validity of resources can be difficult to assess (Hanson and Carlson, 2005; Cafolla, 2006). Third, professional development to support the use of these resources in the classroom is not always available (Hanson and Carlson, 2005; Johnson, 2011; Buhr et al., 2012). Fourth, there may be a lack of sufficient technological institutional support, such as availability of computers, software, or download restrictions (McMartin et al., 2008). Fifth, resource content may not be aligned with state and national standards, an important criterion for K–12 educators (Hanson and Carlson, 2005; Mervis, 2009a; Bangay and Blum, 2010; Wise, 2010; Lynds, 2011). In this paper, we review efforts to support educators in the use of digital educational materials, with a particular focus on the solution of the first two challenges described above.

One way to overcome the problem of accessing reliable and high-quality digital teaching materials is through curated collections of digital resource or digital libraries of educational materials. Digital libraries or collections present resources, otherwise scattered over the Internet, together in a coherent and accessible portal with easy search interfaces (Hanson and Carlson, 2005; Lempinen, 2006). Prominent examples are the collections within the National Science Digital Library (NSDL), the Science Education Resource Center (SERC), and the Multimedia Educational Resource for Learning and Online Teaching (MERLOT) as well as commercial efforts such as lessonplanet.com, tutor.com, net.trekker, learner.com, and Brokers of Expertise.

The introduction of review systems comparable to the scholarly journal review system has been attempted by numerous groups to address the described barrier of variable and unreliable scientific and educational quality of digital resources. Ten prominent examples of review processes for educational material are summarized in Table I.

Providing educators with authoritative and scientifically accurate teaching resources is especially important for publicly

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[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, Colorado 80303, USA
[2]TERC, Cambridge, Massachusetts 02140, USA
[3]Science Education Resource Center (SERC), Carleton College, Northfield, Minnesota 55057, USA
[4]National Center for Science Education (NCSE), Oakland, California 94609, USA
[5]Climate Program Office, National Oceanic and Atmospheric Administration (NOAA), Silver Spring, Maryland 20910, USA
[a]Author to whom correspondence should be addressed. Electronic mail: anne.u.gold@colorado.edu. Tel.: 303-562-4027.

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sensitive subjects including evolution, climate change, and energy, which can lead to controversy and confusion in the classroom. In this paper, we focus on climate and energy topics. How can an educator who may lack knowledge of the underlying science know that an online resource is scientifically accurate, pedagogically useful, and technically robust? Educators have reported being challenged by parents or colleagues when teaching climate science or they opt to teach "both sides" (Wise, 2010; Chasteen, 2011; Johnson, 2011; Buhr et al., 2012). Educators have described a need for high-quality teaching resources in this field (Lynds, 2011; Buhr et al., 2012). The Climate Literacy and Energy Awareness Network (CLEAN) addresses these challenges by providing educators with a collection of rigorously reviewed digital educational materials on these topics.

In this paper, we briefly summarize the scholarly journal peer-review system as well as efforts to modify this established process in the evolving field of educational material review. We then describe existing efforts and previous attempts to build review systems for digital collections of teaching materials in the geosciences. Finally, we present the review system developed by the CLEAN project team and describe how we evolved the educational and scientific review processes from previous efforts.

PEER-REVIEW PROCESS

The Scholarly Peer-Review Process

Peer review is a fundamental pillar of the scientific process and thus of creation and dissemination of knowledge (Hovav and Gray, 2006; Mandviwalla et al., 2008; Harley and Acord, 2011). Its beginnings date back to the 17th century (Kronick, 1990; Mulligan, 2004). The process is well-established for scientific journals and generally follows the model in Fig. 1. The scientific community only accepts new scientific findings or theories after publication in peer-reviewed journals (Mulligan, 2004; Suls and Martin, 2009), which also affects tenure decisions in academic careers (Speier et al., 1999; Siemens, 2001). Therefore, most scientists are intimately familiar with the process both as submitters and reviewers of scientific articles. Criticism of the peer-review process includes the following: It is a slow and expensive process; it lacks inter-reviewer reliability, and there is the possibility that the reviewers may be biased, may abuse the peer review for personal career enhancement, or steal ideas (Harnad, 1998; Møller and Jennions, 2001; Mulligan, 2004; Oxman and Guyatt, 2006; Smith, 2006; Grainger, 2007; Mandviwalla et al., 2008; Suls and Martin, 2009; Harley and Acord, 2011).

Modifications to Scholarly Peer-Review Process in the Digital Age

Scholarly communication has shifted from largely print-based journals to electronic journals (often with a print counterpart) within the last two decades (Tenopir, 2004; Greco et al., 2006; Moghaddam, 2007; Rowlands, 2007). Electronic journals are attractive because they are easy to access, original data is often provided as online supplements, and publication follows quickly after the review process (Liew et al., 2000; Siemens, 2001; Hovav and Gray, 2006). With increasing numbers of electronic journals, alternate models to the traditional peer-review process have been explored by publishers, including 1) mediated open discussions prior to publication, 2) publication of accepted manuscript along with comments by reviewers to increase accountability, and 3) tentative publication of accepted manuscript along with peer reviews for open public comments that can be included before publication (Harnad, 1998; Sumner et al., 2000; Weller, 2000; Mizzaro 2003; Mulligan, 2004; Hovav and Gray, 2006; Smith 2006; Suls and Martin, 2009; Campion and Drazen, 2010). None of these modified models has been widely implemented.

Review Process for Educational Materials

The process of rigorous peer review of educational resources has not been applied consistently and is not as widely accepted in the educational as in the scientific community (Eibeck, 1996; Knight et al., 2004). One reason is that curriculum developers are not producing new cutting-edge content; instead, they repackage authoritative, peer-reviewed scientific knowledge to make it accessible for the target audience (Fincher and Work, 2005). However, repackaging and simplifying established scientific knowledge for a specific audience is nontrivial because oversimplification might lead to the development of misconceptions among students. Thus, a review process to ensure a correct translation of scientific findings into effective teaching materials is crucial. The journal peer-review process is an established model that can inform the development of a review process for educational materials.

Reviewing educational resources poses additional challenges to the review process as compared to the process established for scholarly communication. Educational materials have to be scientifically accurate and current, pedagogically effective, presented in an attractive format, and designed in compliance with effective educational practices (Eibeck, 1996; Ruiz et al., 2007). If published electronically, the reviewers also have to evaluate the technical quality and feasibility as well as usability of the content (Weatherley et al., 2002; Knight et al., 2004; Kastens, 2005). A single reviewer is rarely qualified to assess all of these aspects; thus, a panel of experts is typically required to review educational materials.

Review processes for textbooks exist but are different for textbooks used at the college level than for K–12 textbooks. Publishers of college-level textbooks send the textbooks out for review to scientific experts in the field before publication, leaving the authority of the review in the publishers' hands. In contrast, the K–12 textbook review and adoption process is often regulated by the states.

In the United States, 22 states have established review processes to approve or adopt instructional materials, mainly textbooks (Texas Education Agency, 2010; Phillips, 2011). These review processes are implemented by states' individual boards of education (Finn and Ravitch, 2004; Phillips, 2011). However, California and Texas, which have the largest state populations, traditionally set standards for the adoption process to ensure quality, and materials that meet these standards are frequently adopted by other states. For example, in California the Curriculum Commission appoints instructional material reviewers as well as content review experts. Each reviewer submits an independent review; the publisher and the public can comment before a final decision

regarding adoption of the materials is made (California Department of Education, 2009). Thus, the established review process for educational resources is the effort of a multidisciplinary team, requiring multiple years.

The unlimited and inexpensive digital publishing opportunities of educational resources of different granularities (digital textbooks and full curriculum to single animations and visualizations) challenge this established process (CLRN, 2008; Mardis et al., 2010). Digital educational materials allow much faster publication than complete print textbooks. The short turnaround is particularly important for evolving scientific fields where an adoption process of multiple years may result in materials being already outdated when published (Cafolla, 2006). However, the fast process of digital publication and the absence of an accepted review process make it more difficult for the educators to judge the quality and authority of a resource (Knight et al., 2004). For digital educational resources, the listed author and the digital publisher are the only authorities for the resource quality (Cafolla, 2006).

REVIEW MODELS FOR DIGITAL EDUCATIONAL MATERIALS IN THE GEOSCIENCES

Various efforts have been made to develop review systems for the growing number of digital educational resources that allow a faster turnaround than the textbook review process. Ten prominent examples of review models in the geoscience education community are characterized in Table I.

Seven of the collections listed in Table I were produced for or are accessible through the Digital Library for Earth System Education (DLESE), a collection focused on providing digital learning resources for earth system science topics. DLESE comprises a small reviewed (1,076 resources) and a broad nonreviewed (12,960 resources) collection section (DLESE, 2012). The reviewed collection is only growing slowly as a result of a significant decrease in DLESE funding (Marlino et al., 2008; Fellows, 2009; Mervis, 2009b).

MODEL FOR TRANSPARENT RIGOROUS PEER REVIEW FOR EDUCATIONAL RESOURCES

CLEAN (www.cleanet.org) developed a peer-review process for educational resources by incorporating elements of the review models described previously (Table I) as well as from the scholarly peer-review process. The scope of the CLEAN collection is defined by the Essential Principles of Climate Literacy (USGCRP, 2009) and the internally developed energy awareness principles (CLEAN, 2012). With the publication of the Energy Literacy Principles (DOI, 2012), we are also aligning the collection to these nationally endorsed key ideas. Using this literacy-based approach, CLEAN is curating a collection that covers the breath of relevant online materials for the two subject areas. The CLEAN collection features open-access learning activities, videos, short demonstrations/experiments, visualizations, and modules/units geared toward secondary and postsecondary educators.

CLEAN Review Process

The review process is outlined in Fig. 2, and includes six steps: 1) informal triage during resource harvesting, 2) formal triage, 3) first and 4) second general review, 5) panel review, and 6) expert science review. Resources enter the review process either via addition by a CLEAN review team member or submission via a public form. The CLEAN review team attempts to search all major resource pools to harvest existing materials (step 1). Even though the CLEAN team has screened thousands of digital materials (see Fig. 3), not all the existing resources have been reviewed because new resources are continually being developed, partially as a result of recently increased funding opportunities in climate change education.

Resources entered in the online review tool undergo a brief vetting (step 2) in which the relevance of the resource to the collection is assessed and an initial qualitative recommendation is given. Resources that pass the initial vetting are subject to two rounds of general review (steps 3 and 4), which are documented in the online review tool (Fig. 4). These two general reviews assess three aspects of the resource: scientific accuracy, pedagogic effectiveness, and usability/technical quality. The questionnaire prompts reviewers to consider all aspects that characterize a high-quality resource, including best practices, in the design of educational resources. A unique set of questions was developed for each resource type (activity, video, visualization, demonstration/experiment, module/unit). Reviewers answer specific review questions on a Likert scale, provide comments on strengths and concerns in narrative form, and summarize in an overall rating for each of the three categories. The reviewer then gives an overall qualitative recommendation (low, medium, or high priority), which determines the path a resource takes through the review process. Resources rated to be of medium or high quality move forward to the next step, whereas any resource rated low priority does not move on. The CLEAN review team consists of six in-house reviewers, experienced middle school, high school, and college-level educators as well as scientists.

Resources that pass the two general reviews are presented to a panel of four reviewers (step 5). The panels include at least one climate or energy scientist, experienced educators, and a CLEAN team reviewer. Modeled after the National Science Foundation panel review process, each reviewer is assigned a quarter of the panel resources to present during the review panel meeting for discussion. The panel discusses each resource, considering the initial reviews and adding their own insights. Finally, the panel recommends whether or not a resource should be included in the CLEAN collection. The panel also has the opportunity to forward a resource to the CLEAN editorial board for further discussion and final decisions in case some issues remain unresolved after the discussion. Bringing together educators and scientists in a panel ensures that attention is paid to both scientific accuracy and pedagogic effectiveness. All the reviewer comments are summarized as annotations (notes to the user), which are finalized by the panel if a resource passes and then provided on the public CLEAN page separately for each resource in the collection (Fig. 5). Review

TABLE I: Summary of ten prominent review processes developed in the geosciences.

	DLESE Community Review System	DLESE Peer-Review System for Digital Geoscience Education Resources	DLESE—Partnership Review System
Collection audience	Educators; learners at all levels	Earth science instructors	User of JESSE and UMADA[3]
Thematic focus of collection	Geosciences	Geosciences	Geosciences
Resource type reviewed	Activities	Variety of resource types, mainly activities	Complex educational resources-like modules
Review steps	Community reviews,[4] specialist review, robustness review, editorial board, developer contact	Reviews,[4] panel review, developer contact	Reviews (completed online addressing parts of resource)
Number of reviewers	13+	2 plus panel	3–6
Expertise of reviewers	Educators, scientists	Geoscience and geoscience education experts	Domain experts
Written reviews	Yes	Yes	Yes, online comments
Classroom tests	Yes	No	No
Test of technical quality	Yes	Yes	No, peer reviewers must be able to access and use it
Review panels	No	Yes	No (online group discussions)
Public comments?	Yes	No	No
Iteration with developer	Yes	Yes	Yes
Reviewer comments posted online?	Yes	No	No
Star rating of resources	No	Yes	No
How to contribute	Resources from DLESE broad collection, reviewed by community members	Provided by selected collections	Chosen by collection developer
Number of reviewed resources in collection	160	155	2 in JESSE
Collection growing?	No	No	No
References	Kastens, 2001, 2005; Kastens et al., 2005; Arko et al., 2006; Kastens and Holzman, 2006	Mayhew and Hall, 2007	Weatherley et al., 2002
Collection URL	http://www.dlese.org/dds/histogram.do?group=subject&key=crs	http://serc.carleton.edu/introgeo/index.html	Not longer available

[1]American Association of the Advancement of Science (AAAS)—Project 2061.
[2]The Climate Change collection (McCaffrey, 2009) was a pilot test for the CLEAN collection.
[3]JESSE—Journal of Earth System Science Education; UMADA—Unidata Meteorological Applications Discussion Area (data visualization software).
[4]Based on review criteria defined in Manduca and Mogk (2000).
[5]Science Educator's Guide to Selecting High Quality Instructional Materials. Project 2061 is not building a collection themselves but their review system was adopted by Phenomena and Representations for the Instruction of Science in Middle Schools (PRISM) project features a total of 324 digital middle school resources in 6 different topic areas, 134 of which are focused on earth science and ecology (PRISM, 2009).
[6]NASA Science Mission Directorate (SMD) education digital library is in development (planned release, Fall 2012).
[7]Under development.

panels have been conducted during face-to-face meetings as well as virtually.

The scientific accuracy of a resource is assessed during the general reviews. However, in order to ensure high scientific quality, CLEAN solicits an additional science review by a specialist in the field for each resource (step 6). This expert scientist comments on the scientific content of the resource and recommends whether or not to include the resource in the CLEAN collection. Comments from the scientist are posted as annotations on the public resource page of accepted resources (Fig. 5). Each scientist is asked to keep the target grade level of the resource in mind when

TABLE I: Extended.

MERLOT—Multimedia Educational Resource for Learning and Online Teaching	NASA Earth and Space Science Education Product Review	AAAS—Project 2061[1]	Climate Change Collection[2]
Higher education faculty and students	Grades K–12, college, and informal educators	Grades K–12 educators	Grades 6–14 educators
Geosciences and other subject areas	Earth and space sciences	Science	Climate change
Wide variety of learning resources (19 different types, e.g., activities, tutorials, simulations)	All NASA educational resources (e.g., lesson plans, curriculum, exhibits, games, courses)	Variety of instructional materials	Variety of resources
Triage, reviews, editorial board decision, developer contact	Reviews, panel discussion, NASA forum and/or NASA consultation, developer contact	Review of learning goals, of resource effectiveness, summary	Reviews,[4] panel discussion
2 plus editor	5–7	2	2–3
Faculty member of discipline	Formal and informal educators, scientists	K–12 educators	Teachers, climatologist, cognitive scientist
Yes	Yes	Yes	Yes
No	No, most resources classroom-tested before submission	No	No
No, peer reviewers must be able to access and use it	No, peer reviewers must be able to access and use it	No, peer reviewers must be able to access and use it	No, peer reviewers must be able to access and use it
No	Yes	No	Yes
Yes	No	No	No
Yes	Yes	Not available	No
Yes	No	Not available	Yes
Yes	No	Not available	Yes
User suggestion only	Submitted by developer	Not available	Chosen by reviewers
3,354 total (geoscience: 4)	~800	Not available[5]	40
Yes	Yes	Not available[5]	No
Malloy and Hanley, 2001; Cafolla, 2006; http://taste.merlot.org/peerreviewprocess.html	http://nasareviews.strategies.org/	http://www.project2061.org/publications/EducatorsGuide/online/	http://serc.carleton.edu/climatechange/index.html
www.merlot.org	http://www.dlese.org/dds/histogram.do?group=subject&key=eserev; http://teachspacescience.org	Not available[7]	http://serc.carleton.edu/climatechange/summary.html

judging its scientific quality because simplifications are often necessary for complex science topics in resources for younger students. The scientist also notes if a resource addresses cutting-edge science and needs to be revisited regularly to check for currency of the science content. The pedagogic effectiveness is assessed by master teachers and college-level faculty during the two general reviews and the review panel.

CLEAN makes a concerted effort to engage with resource developers. Unlike a journal peer-review process where authors submit articles for peer review, the initial CLEAN collection primarily features digital resources that were identified by the CLEAN team members from a wide range of online resource pools (Fig. 2). The CLEAN team contacts developers of resources that have passed the full review process and provides them with a "CLEAN Selected" logo (Fig. 6) to place on their accepted resource. CLEAN now also offers developers the opportunity to choose an iterative review process. In this iterative process, the CLEAN team provides feedback from the reviewers to the developer of a resource through the review process. Developers address the comments and implement changes into the resource prior to acceptance in the collection. Developers of resources that fail the review process can resubmit the resources for review after reviewer concerns are addressed.

TABLE I: Extended.

	DWEL—Digital Water Library Project	GLOBE—Global Learning and Observations to Benefit the Environment	CLEAN—Climate Literacy and Energy Awareness Network Collection
Collection audience	Grades K–12 and informal educators	Middle school and high school educators	Grades 6–16 and informal educators
Thematic focus of collection	Science, economics, policy of water	Earth system education	Climate and energy science
Resource type reviewed	Variety of resources, mainly activities	Variety of resources, mainly activities	Activities, visualizations, videos, demonstrations, experiments, modules, units
Review steps	Vetting, resource type specific reviews[4]	Reviews,[4] input from GLOBE community, developer feedback, NASA product review	Vetting, general reviews, review panel, expert science review, developer contact[6]
Number of reviewers	2	7	5–7
Expertise of reviewers	K–12 and informal science educators	Classroom teachers, educators, expert scientist	Scientists, formal and informal educators
Written reviews	Yes	Yes	Yes
Classroom tests	No	Yes	No
Test of technical quality	No, peer reviewers must be able to access and use it	Yes	No, peer reviewers must be able to access and use it
Review panels	No	No	Yes
Public comments?	Yes	No	Yes
Iteration with developer	No	Yes	Yes
Reviewer comments posted online?	No	No	Yes
Star rating of resources	No	No	No
How to contribute	Teachers identify resources	GLOBE-produced resources	Submitted by developer, CLEAN team collected
Number of reviewed resources in collection	370	>100	480
Collection growing?	No	Yes	Yes
References	Moore and Aivazian, 2002; Aivazian et al., 2003; http://www.dlese.org/Metadata/collections/scopes/dwel-scope.php	http://classic.globe.gov/fsl/html/templ.cgi?dlesescope&lang=en&nav=0	http://cleanet.org/clean/about/review.html
Collection URL	http://www.dlese.org/dds/histogram.do?group=resourceType&key=dwel	www.globe.gov	http://cleanet.org/clean/educational_resources/index.html

Development of CLEAN Review Process and Criteria

In the multistage CLEAN review process, both educators and scientists judge the quality of an educational resource. The process builds on previously developed guidelines from the other review processes listed in Table I and pilot-tested in the climate change collection (McCaffrey, 2009). The CLEAN process combines the strengths of the different efforts into a new rigorous review system.

All review activities and comments are captured in a custom-built online tool, which has been refined over the first two project years. For any given resource, five to seven reviewers with different areas of expertise (master teachers, college-level faculty, and scientists) evaluate and provide comments throughout the process to ensure that only the best resources that are in scope with the collection pass through the system filters. The in-house CLEAN review

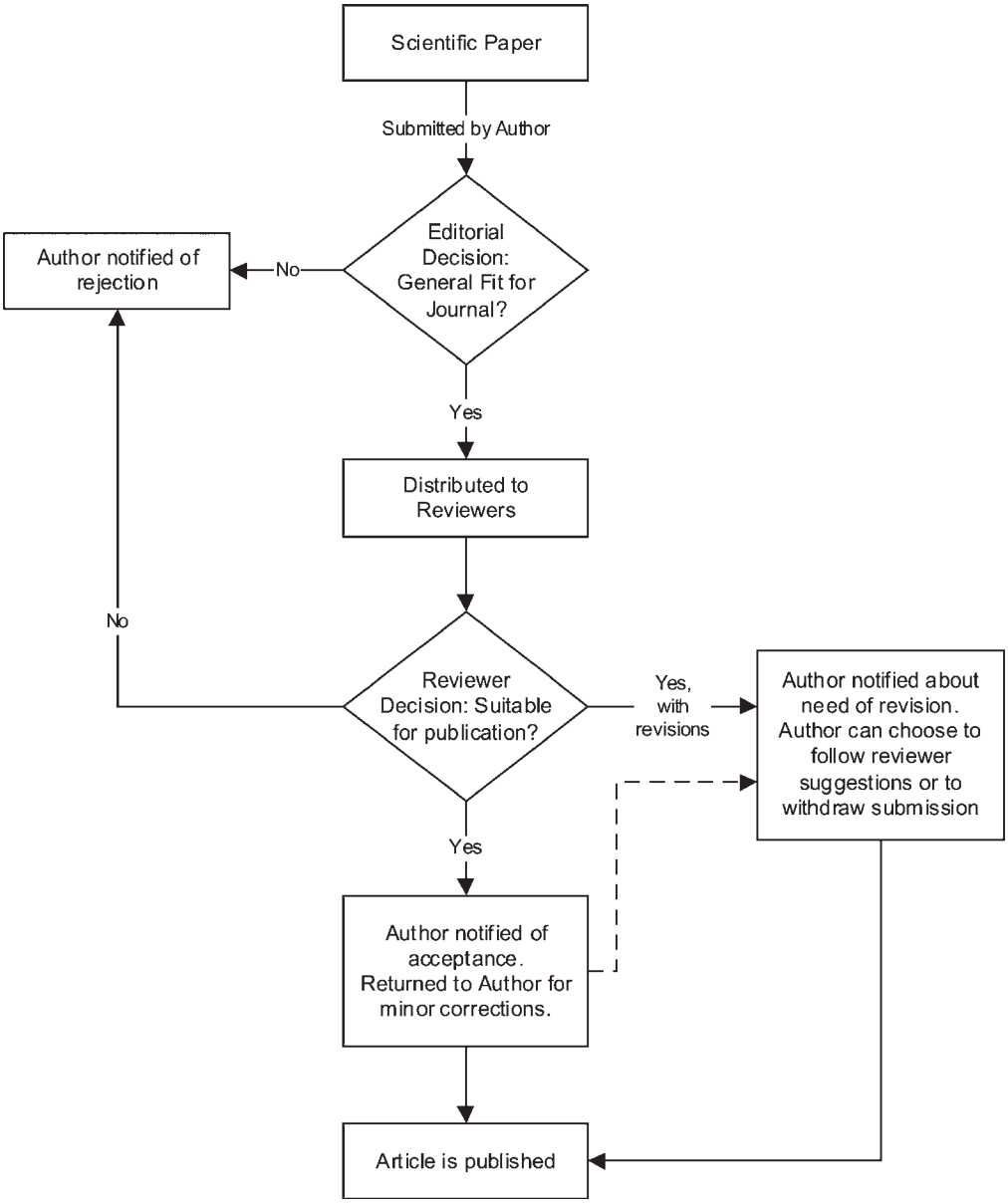

FIGURE 1: Peer-Review Process for Scientific Journal Articles. Author submits previously unpublished manuscript to a journal's editorial office. Editors decide on general fit of the manuscript and send it out to multiple reviewers. Reviewers are asked to evaluate the manuscript and return it to the editor with comments and recommendation about acceptance to the journal. Based on the reviews, the editor decides whether or not to publish the manuscript or if revisions are necessary before publication.

team completes the general reviews; the panel brings external reviewers together. The review process typically takes 3–5 months for a given resource.

As mentioned above, we have developed a unique set of questions (review criteria) for each resource type that we review. An initial attempt was made to measure interreviewer reliability with each of these review criteria. However, many questions are subjective (e.g., "Is the resource engaging and motivating for students?"), making it difficult to implement quantitative measures. Thus, all CLEAN review outcomes are qualitative. Participation of CLEAN team members in the development and refinement of the review criteria and process has established a common understanding of each review instrument. The six-step CLEAN review process is supported by a custom-built technical infrastructure that documents and archives the process for each resource (Fig. 4).

LESSONS LEARNED

Definition of Collection Scope

Review teams initially struggled to determine which resources should be included in the CLEAN collection. One problem we faced was that the literacy documents that define

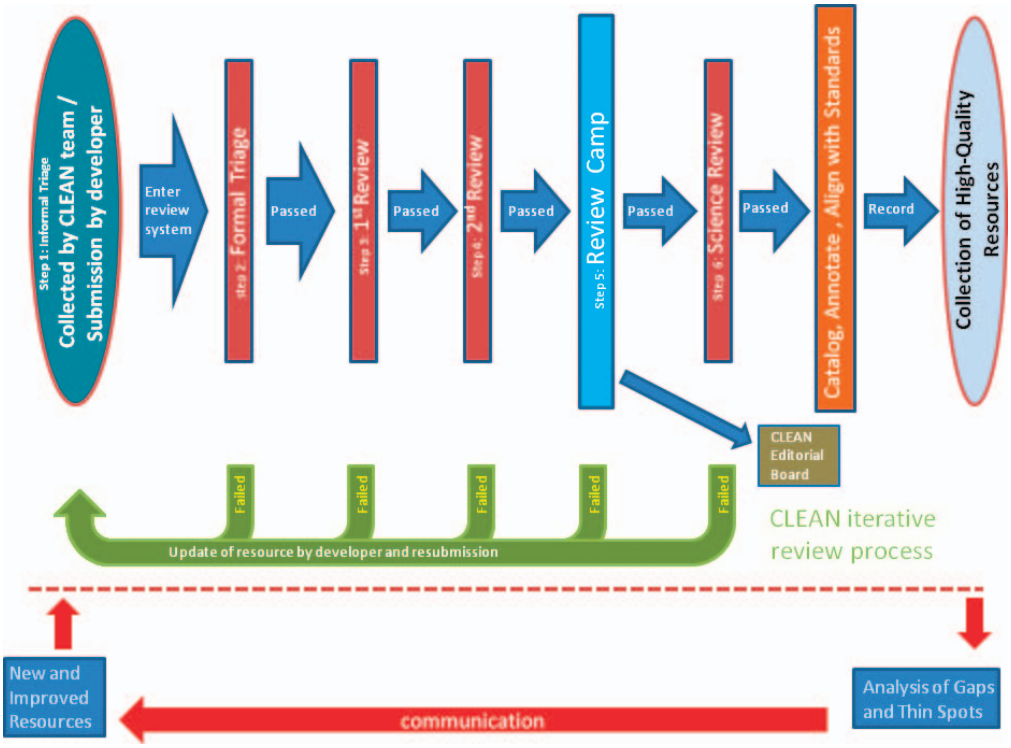

FIGURE 2: CLEAN Review Process. An initial informal triage step (1) during resource harvesting is followed by a vetting step (2) that ensures that a resource is compatible with the collection scope; two separate written reviews (3 plus 4) follow. A panel review (5) considers all previous reviews in a panel discussion before acceptance in the collection. A final quality check by an expert scientist marks the last hurdle for its inclusion in the CLEAN collection (6).

the collection scope are knowledge statements and not a simple list of learning goals, and hence not an easy guide to finding relevant resources. Internal discussions and the development of a comprehensive set of climate and energy topic terms ("vocabularies") helped the team define the collection scope (CLEAN, 2011). The clearly defined collection scope has also allowed us to identify gaps and thin spots in the collection, which again have informed the CLEAN resource-collecting efforts as well as resource developers.

Addressing Needs of Diverse Audiences

CLEAN strives to support educators in teaching diverse audiences. However, the review team found it challenging to define the needs of a diverse audience and determine how to address this nebulous group in the review criteria questionnaire because each of the individual sectors within the diverse audience has specific needs. Initially, CLEAN experimented with tagging resources that seemed to appeal to a specific underrepresented audience (such as English language learners, Native Americans, Hispanics), similar to the tagging implemented by other efforts (Kastens et al., 2005). However, the results were not satisfying. Instead, the team added new review questions to focus the reviewers' attention on these aspects. Information for specific audiences is included in the annotations.

Addressing the specific needs of different diverse audiences has proved to be prohibitively time consuming. If the task was to be done well, CLEAN would have to bring in experts for each diverse audience. Furthermore, most aspects that make a resource accessible to a diverse audience (e.g., using hands-on and inquiry-based instruction, adding visuals, limiting text) make it more accessible to all students.

Challenge: Obtaining Expert Science Reviews

As we have built the collection, it has proven difficult to obtain expert science reviews because the range of expertise required was daunting. Soliciting expert reviews is time consuming because each resource has to be matched individually with a specialist. Expert science reviews usually take between 20 and 60 minutes and are therefore less time consuming than typical journal reviews. CLEAN asks scientists to complete the reviews as part of a service to science education and does not offer compensation. Unlike the review of scientific papers, review of educational resources is not generally recognized as a merit for an academic career. We are still working on an efficient process of soliciting expert reviews, increasing our database of potential expert science reviewers, and matching experts with reviews without frequently turning to the same people. We have engaged scientists during professional meetings, which is a promising way of recruiting expert science reviews; however, this process still needs refinement.

Communication with Resource Developers

The CLEAN team is still experimenting with approaches for engaging resource developers. Resource developers have

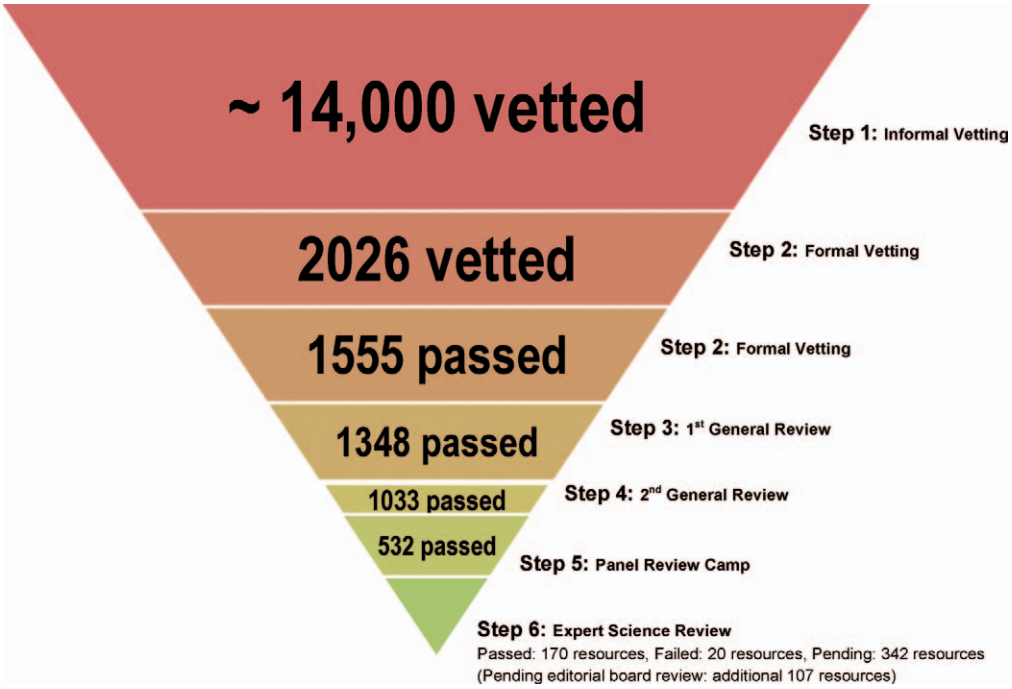

FIGURE 3: CLEAN Review Process Outcomes. Summary of CLEAN review outcomes for review period March 2012–May 2012.

different levels of interest in and availability for the CLEAN process. Some developers are very engaged and want to be involved in the review process. Others have developed resources with the CLEAN review criteria in mind and are willing to update their resources based on feedback from CLEAN reviews. Some resources we reviewed have been developed and published under funding that has expired or the resource developers have moved on. These developers are not typically available for a dialogue with the CLEAN team and often lack funding to implement suggested changes. Because of the variety of availability on the part of the developers, the level of communication with each one varies. Ideally, the CLEAN review process will evolve into a submission peer-review process similar to a journal article submission, where developers are willing to engage in an iterative review process to improve their resource in order to have it accepted into the CLEAN collection.

Dynamic Digital Environment

One challenge faced by CLEAN and other reviewed collections is the dynamic landscape of digital resources—new resources are constantly being created and old ones removed. The removal of resources is particularly problematic for CLEAN because we do not host any of the resources. We provide information about the resource in our annotations and the direct URL to the resource. In addition to disappearing, resources sometimes deteriorate or evolve (Weller, 2000; Kastens et al., 2005). Automatic link-checking programs facilitate repair of broken links directed to the resource. However, they do not address broken links or other deterioration within the resource. To address the challenge, we note the dates the resource was developed and last updated during the review. We currently do not have a mechanism to flag resources that were changed after the review.

Scalability of Review Process

The CLEAN review process was developed for a small collection with a clearly defined thematic scope. The staff-intensive CLEAN review process was not designed to be scalable to a large collection that adds several thousand new catalog records annually. However, moving from resource-intensive face-to-face review camps to virtual camps reduced the necessary funds for the review process. In this sense, the review process is very much like the peer-review process of a journal that conducts reviews of only a few hundred manuscripts per year. Review processes for much larger collections of educational materials have to be simpler and cannot achieve the same rigorous level of curation as CLEAN.

Sustainability

The CLEAN collection and the processes and tools used to build it have been developed with the needs of the broader community—ranging from the funding agencies to individual educators—in mind. The longer-term sustainability of CLEAN is dependent on it continuing to meet the needs of this community. We have defined what is needed to maintain at a minimum level CLEAN core activities and several tiers of activities that would more fully develop the CLEAN core and would expand on and leverage the CLEAN collection and services. This has helped us define the various avenues through which we can develop partnerships to fund the core activities, develop proposals to extend on CLEAN core activities, and provide review services to groups who are developing materials. We are currently pursuing these partnerships to develop lines of continuing funding.

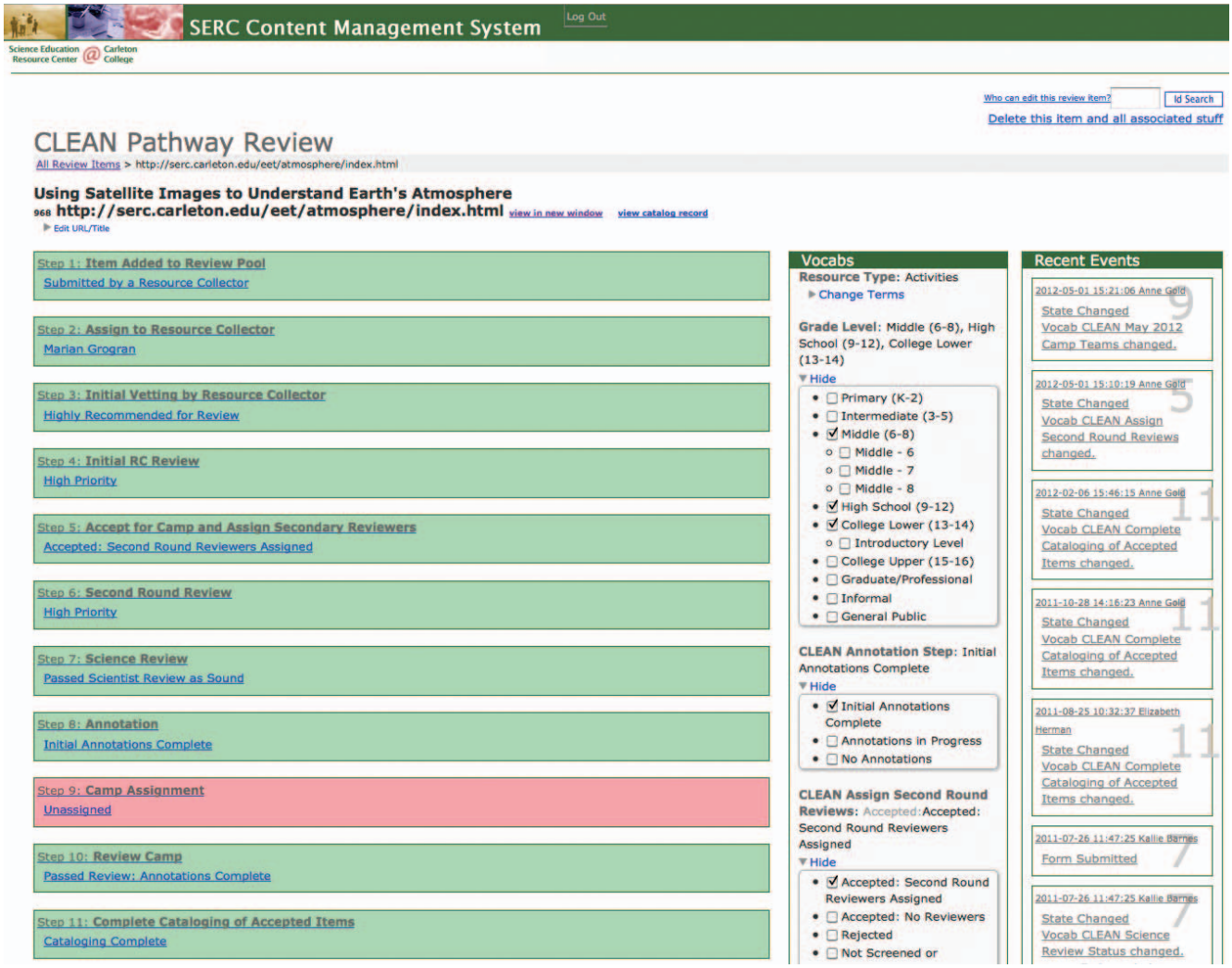

FIGURE 4: Screenshot of CLEAN Review Tool. Custom-built review database in which all review information is stored separately for each resource. All the reviews, comments, and ratings are digitally available.

CONCLUSION

Easy and inexpensive digital publishing leads to a vastly growing number of digital educational materials, often with unclear credibility, making it difficult for educators to evaluate the quality. Reviewed collections of digital educational materials build trust in educators and minimize the time educators have to spend searching for high-quality and relevant materials.

The scholarly journal peer-review process as well as the formal textbook adoption processes are established models that have informed the development of review processes geared toward digitally available teaching resources. One key difference between reviewing digital educational resources and the scientific journal peer-review process is that journal articles are published in the media owned by the company leading the review process and only after the author successfully completes the review process for the article. On the other hand, digital educational resources are usually published on the Web site of the developer. Whether or not they pass a review process does not affect the digital publication itself. The other key difference is that multiple reviewers (scientists and educators) are needed to evaluate the quality of educational resources.

The CLEAN project has developed a set of resource-type-focused review criteria and a robust peer-review process to evaluate educational resources by incorporating aspects of previously developed educational review processes, by addressing the specific needs for educational materials, and by following the established scientific peer-review process in bringing scientists and educators together to review resources using a panel. Educators of middle schools, high schools, and colleges alike are excited about the content of the CLEAN collection (Table II), specifically because both educators and scientists have reviewed the resources thoroughly. CLEAN provides what they need to teach about climate and energy topics at different instructional levels and the rigorous curation reduces the time they have to spend looking for effective and accurate resources.

CLEAN uses a literacy-based approach to curate a well-rounded collection containing resources to teach all the key ideas as laid out by the climate literacy principles and the

Using Satellite Images to Understand Earth's Atmosphere

http://serc.carleton.edu/eet/atmosphere/index.html

Todd Ensign, et. al., Earth Exploration Toolbook, TERC

In this Earth Exploration Toolbook chapter, students select, explore, and analyze satellite imagery. They do so in the context of a case study of the origins of atmospheric carbon monoxide and aerosols, tiny solid airborne particles such as smoke from forest fires and dust from desert wind storms. They use the software tool ImageJ to animate a year of monthly images of aerosol data and then compare the animation to one created for monthly images of carbon monoxide data. Students select, explore and analyze satellite imagery using NASA Earth Observatory (NEO) satellite data and NEO Image Composite Explorer (ICE) tool to investigate seasonal and geographic patterns and variations in concentration of CO and aerosols in the atmosphere.

Activity takes about three to four class periods. Computer and Internet access required.

Discuss this Resource»
Learn more about Teaching Climate Literacy and Energy Awareness»

Notes From Our Reviewers

The CLEAN collection is hand-picked and rigorously reviewed for scientific accuracy and classroom effectiveness. Read what our review team had to say about this resource below or learn more about how CLEAN reviews teaching materials

Teaching Tips | Science | Pedagogy | Technical Details

Teaching Tips

- Introduce students to ImageJ before beginning the exercise.
- Instructors should emphasize the effect of aerosols on the energy budget and climate.
- Suggest pairing students for activity.

About the Science

- Excellent use and application of science from remote sensing data with a problem-based scenario.
- Makes use of the type of tools scientists use to analyze satellite images to study change.

About the Pedagogy

- Hands-on exercise uses NEO data to explore carbon monoxide concentrations and aerosols.
- Good organization of learning materials and a logical learning sequence leads students to analysis and understanding of complex data sets.
- Instructions are clear, thorough, and well-written.
- The case study provides good background information for students (and teachers).
- Excellent going further activities for advanced students.
- Hands-on exercise uses NEO data to explore carbon monoxide concentrations and aerosols.
- **This resource engages students in using scientific data.**
  See other data-rich activities

Technical Details/Ease of Use

- The "show me" feature that helps students through problems and procedures using software is just exemplary and allows students to check their progress frequently throughout the activity.

Topics

Atmospheric Circulation
See more on this topic.

Aerosols
See more on this topic.

Atmospheric Composition
See more on this topic.

Grade Level

Middle (6-8)
See more at this grade level.

High School (9-12)
See more at this grade level.

College Lower (13-14)
See more at this grade level.

Climate Literacy

About Teaching Climate Literacy

▸ 2e (see details)
About Teaching Principle 2
Other materials addressing 2e

▸ CIi (see details)
About Teaching Principle C
Other materials addressing CIi

▸ 6c (see details)
About Teaching Principle 6
Other materials addressing 6c

Benchmarks for Science Literacy

Learn more about the Benchmarks

▸ Processes that Shape the Earth-7 (Middle 6-8) (see details)
Explore the concept map related to this benchmark

▸ Energy Sources and Use-11** (Middle 6-8)

FIGURE 5: Example of CLEAN Public Catalog Record. CLEAN collection hosts a Web page (catalog record) per resource with resource URL, content summary, a summary of reviewer comments (annotations), and teaching tips, along with relevant and searchable metadata such as appropriate grade level, standard and benchmark alignment, and relevant benchmark maps.

FIGURE 6: CLEAN Selected Logo. Quality stamp that can be placed on the original resource Web site by the developer to indicate that resource passed the CLEAN review process.

energy literacy principles. This literacy-based approach facilitates self-assessment of how well the collection addresses primary topics and ideas at different grade levels and allows identification of gaps in the collection with respect to addressing all the climate literacy and energy literacy essential principles and fundamental concepts.

Services that CLEAN offers to resource developers include review of resources, dissemination of geoscience educational resources beyond the originally intended audience, and analysis of the gaps in the collection's resources as well as guidance on what makes a high-quality educational resource. The investment in the CLEAN review process has built a community of diverse experts who can now share their resources and expertise learned through participation in the CLEAN review process with the broader community. The CLEAN review process can be adapted for other thematic collections because most review questions identify high-quality teaching materials and are not thematically focused on climate and energy science.

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REFERENCES

Aivazian, B.L., Geary, E., Khoo, M., Sumner, T., and Ireton, S. 2003. Serving K–12 education with DWEL: Knowledge quest. *Journal of American Association of School Librarians*, 31(3):21–22.

Arko, R.A., Ginger, K.M., Kastens, K.A., and Weatherley, J. 2006. Using annotations to add value to the digital library for education. *D-Lib Magazine*, 12(5). Available at http://www.dlib.org/dlib/may06/arko/05arko.html#Top (accessed 2 May 2012).

Bangay, C., and Blum, N. 2010. Education response to climate change and quality: Two parts of the same agenda? *International Journal of Education Development*, 30:359–368.

Borgman, C.L., Abelson, H., Dirks, L., Johnson, R., Koedinger, K.R., Linn, M.C., Lynch, C.A., Oblinger, D.G., Pea, R.D., Salen, K., Smith, M.S., and Szalay, A. 2008. Fostering learning in the networked world: The cyberlearning opportunity and challenge. A 21st century agenda for the National Science Foundation. Report of the NSF Task Force on Cyberlearning, p. 59. National Science Foundation, Arlington, VA.

Buhr, S., Lynds, S., and Ledley, T. Navigating climate science in the classroom: Teacher preparation, perceptions and practices. *Journal of Geoscience Education*, forthcoming.

Cafolla, R. 2006. Project MERLOT: Bringing peer review to Web-based educational resources. *Journal of Technology and Teacher Education*, 14(2):313–323.

California Department of Education. 2009. Instructional material

TABLE II: Testimonies from educators about using the CLEAN Collection and its content (Inverness Research, 2011).

"I like that when you go to the education resources, it's easy to find a lesson plan, and I like the way the information is laid out. I like all the reputable references. This is a real positive for me and the teachers I am teaching. The fact that the material is peer reviewed is very helpful."
"The reviewed educational resources will keep me coming back."
"The information on the [CLEAN] website takes the politics out of it. The scientists have checked the contents of this site, and this is helpful for my teachers, some of whom are afraid to teach the subject for fear of getting in trouble. The materials are peer reviewed and accurate. I don't use Google to find materials like the ones I am looking for on CLEAN and I don't want my students using it either."
"They [CLEAN resources] all look like things I would implement. They all appear to be ready to go, and I have confidence in them because they've been vetted."
"This [CLEAN collection] is as good as I've seen and the quality of the activities seems substantial . . . ."

adoption. Available at: http://www.cde.ca.gov/ci/cr/cf/imagen.asp (accessed 2 May 2012).

Campion, E.W., and Drazen, J.M. 2010. Peer review journals in the digital age. *Arch Bronconeumologia*, 46(11):569–570.

Chasteen, S. 2011. Learn more about climate. Teacher survey on climate education summary prepared for Office of University Outreach at University of Colorado, Boulder, p. 24.

CLEAN (Climate Literacy and Energy Awareness Network). 2011. CLEAN climate and energy vocabularies. Available at http://cleanet.org/clean/about/climate_energy_.html (accessed 2 May 2012).

CLEAN (Climate Literacy and Energy Awareness Network). 2012. Energy awareness principles. Available at http://cleanet.org/clean/about/energy_awarenes.html (accessed 2 May 2012).

CLRN (California Learning Resource Network). 2008. Digital textbook initiative. Available at http://www.clrn.org/fdti/ (accessed 2 May 2012).

DLESE (Digital Library for Earth System Education). 2012. Browse resources and collections. Available at http://www.dlese.org/dds/histogram.do?group=subject (accessed 2 May 2012).

DOI (U.S. Department of Energy). 2012. Energy literacy. Essential Principles and Fundamental Concepts for Energy Education. Available at http://library.globalchange.gov/energy-literacy-essential-principles-fundamental-concepts-for-energy-education (accessed 2 May 2012).

Eibeck, P.A. 1996. Criteria for peer-review of engineering courseware on the NEEDS database. *IEEE Transactions on Education, Special Issue on the Application of Information Technologies to Engineering and Science Education*, 39(3):381–387.

Fellows, J. 2009. An optimistic read on digital libraries. *Science*, 323:1168–1169.

Fincher, R.M.E., and Work, J.A. 2005. The scholarship of teaching in health science schools. *Journal of Veterinary Medical Education*, 32:1–4.

Finn, C.E., and Ravitch, D. 2004. The mad, mad world of textbook adoption. New York: Thomas Fordham Foundation, p. 77.

Grainger, D.W. 2007. Peer review as professional responsibility: A quality control system only as good as the participants. *Biomaterials*, 28:5199–5203.

Greco, A., Wharton, R., Estelami, H., and Jones, R. 2006. The state of scholarly journal publishing: 1981–2000. *Journal of Scholarly Publishing*, 37:155–214.

Hanson, K., and Carlson, B. 2005. Effective access: Teachers' use of digital resources in STEM teaching. Newton MA: Gender, Diversities & Technology Institute, Education Development Center, Inc., p. 97.

Harley, D., and Acord, S.K. 2011. Peer review in academic promotion and publishing: Its meaning, locus, and future. Center for Studies in Higher Education, University of California, Berkeley. Available at http://escholarship.org/uc/item/1xv148c8 (accessed 2 May 2012).

Harnad, S. 1998. The invisible hand of peer review. *Nature* [online, 5 Nov. 1998]. Available at http://www.nature.com/nature/webmatters/invisible/invisible.html?iframe=true&width=100%&height=100% (accessed 2 May 2012).

Hovav, A., and Gray, P. 2006. Academic electronic journals: Past, present, and future. *Advances in Computers*, 67:131–175.

Inverness Research. 2011. CLEAN informant interviews. Summary of responses (unpublished report). Inverness Research, p. 50.

Johnson, R. 2011. Climate change education in K-12: Teacher preparation, understanding, needs and concerns. Available www7.nationalacademies.org/bose/1CCEW2_Roberta_Johnson.pdf (accessed 2 May 2012).

Kastens, K. 2001. Another node on the Internet. *Computers & Geosciences*. 27:375–378.

Kastens, K. 2005. The DLESE community review system: Gathering, aggregating, and disseminating user feedback about the effectiveness of Web-based educational resources. *Journal of Geoscience Education*, 53:37–43.

Kastens, K., DeFelice, B., Devaul, H., DiLeonardo, D., Ginger, K., Larsen, S., Mogk, D., and Tahirkheli, S. 2005. Questions & challenges arising in building the collection of a digital library for education: Lessons from five years of DLESE. *D-Lib Magazine*, 11(11). Available at http://www.dlib.org/dlib/november05/kastens/11kastens.html (accessed 2 May 2012).

Kastens, K.A., and Holzman, N. 2006. The digital library for earth system education provides individualized reports for teachers on the effectiveness of educational resources in their own classrooms. *D-Lib Magazine*, 12(1). Available at http://www.dlib.org/dlib/january06/kastens/01kastens.html (accessed 2 May 2012).

Knight, C.L., Sakowski, H.A., Houghton, B.L., Laya, M.B., and DeWitt, D.E. 2004. Developing a peer review process for Web-based curricula. Minting a new coin for the realm. *Journal of General Internal Medicine*, 19:594–598.

Kronick, D.A. 1990. Peer review in 18th century scientific journalism. *Journal of the American Medical Association*, 263:1321–1322.

Lempinen, E.W. 2006. Digital architects ponder the library of the future. *Science*, 314:1256–1257.

Liew, C.L., Foo, S. and Chennupati. 2000. A study of graduate student end-users' use and perception of electronic journals. *Online Information Review*, 24(4):302–315.

Lynds, S. 2011. CLEAN informant invitation survey results. Descriptive data internal evaluation report (unpublished). Inverness Research. p. 75.

Malloy, T.E., and Hanley, G.L. 2001. MERLOT: A faculty-focused Web site of educational resources. *Behavior Research Methods, Instruments & Computers*, 33(2):274–276.

Manduca, C.A., and Mogk, D.W. 2000. DLESE: The community plan. Norman, OK: University of Oklahoma, p. 44.

Mandviwalla, M., Patnayakuni, R., and Schuff, D. 2008. Improving the peer review process with information technology. *Decision Support Systems*, 46:29–40.

Mardis, M., Everhart, N., Smith, D., Newsum, J., and Baker, S. 2010. From paper to pixel: Digital textbooks and Florida's schools. Available at www.palmcenter.fsu.edu/documents/digitaltextbooks_whitepaper.pdf (accessed 2 May 2012).

Marlino, M., Sumner, T., Kelly, K., and Wright, M. 2008. When the music is over. *In*: Skinner, K., Halbert, M., and Battle, M. eds., Strategies to sustaining digital libraries. Atlanta, GA: Emory University Digital Library Publications, p. 97–111.

Mayhew, M.A., and Hall, M.K. 2007. Field test of a peer review system for digital geoscience education resources. Abstract no. ED51B-0408 for American Geophysical Union, fall meeting, 2007. Washington, DC: American Geophysical Union.

McCaffrey, M.S. (2009). The climate change collection. Available at: http://serc.carleton.edu/climatechange/index.html (accessed 2 May 2012).

McMartin, F., Iverson, E., Wolf, A., Morril, J., Morgan, G., and Manduca, C. 2008. The use of online digital resources and educational digital libraries in higher education. *International Journal on Digital Libraries*, 9:65.

Mervis, J. 2009a. NSF rethinks its digital library. *Science*, 3223:54–58.

Mervis, J.D. 2009b. New landscape for the earth sciences. *Science*, 323:55.

Mizzaro, S. 2003. Quality control of scholarly publishing: A new proposal. *Journal of the American Society for Information Science and Technology*, 54:989–1005.

Moghaddam, G.G. 2007. Archiving challenges of scholarly electronic journals: How do publishers manage them? *IEEE Serials Review*, 33:81–90.

Møller, A.P., and Jennions, M.D. 2001. Testing and adjusting for

publication bias. *TRENDS in Ecology & Evolution,* 16(10):580–586.

Moore, J.D., and Aivazian, B. 2002. The Digital Water Library Project (DWEL): a NSDL K-12 collection. Geoscience and Remote Sensing Symposium. *IGARSS 2002 IEEE International*, 1:533–535.

Mulligan, A. 2004. Is peer review in crisis? *Perspectives in Publishing*, 2:2–6.

Oxman, A.D., and Guyatt, G.H. 2006. The science of reviewing research. *Annals of the New York Academy of Science*, 703:125–134.

Phillips, M. 2011. Determinants of state textbook selection policies and book content. Paper presented at the Public Choice Conference, March 10–13 2011, San Antonio, TX. Available at http://www.pubchoicesoc.org/papers_2011/Phillips.pdf (accessed 2 May 2012).

PRISM (Phenomena and Representations for Instruction of Science in Middle Schools). 2009. About PRISM. Available at http://prisms.mmsa.org/about.html (accessed 2 May 2012).

Rowlands, I. 2007. Review: Electronic journals and user behavior: A review of recent research. *Library & Information Science Research*, 29:369–396.

Ruiz, J.G., Candler, C., and Teasdale, T.A. 2007. Peer reviewing e-learning: Opportunities, challenges, and solutions. *Academic Medicine*, 82(5):503–507.

Siemens, R. 2001. The credibility of electronic publishing. A report to the Humanities and Social Sciences Federation of Canada. Available at http://web.viu.ca/hssfc/final/credibility.htm (accessed 2 May 2012).

Smith, R. 2006. Peer review: a flawed process at the heart of science and journals. *Journal of the Royal Society of Medicine*, 99:178–182.

Speier, C., Palmer, J., Wren, D., and Hahn, S. 1999. Faculty perceptions of electronic journals as scholarly communication: A question of prestige and legitimacy. *Journal of the American Society for Information Science*, 50(6):537–543.

Suls, J., and Martin, R. 2009. The air we breathe: A critical look at practices and alternatives in the peer-review process. *Perspectives on Psychological Science*, 4(1):40–50.

Sumner, T., Buckingham Shum, S., Wright, M., Bonnardel, N., and Chevalier, A. 2000. Redesigning the peer review process: A developmental theory-in-action. *In:* Proc COOP 2000: Fourth International Conference on the Design of Cooperative Systems, Sophia Antipolis, France, May 23–26.

Tenopir, C. 2004. Online database-online scholarly journals: How many? *Library Journal*. Available at http://www.criticasmagazine.com/lj/technologyonlinedb/871398-299/story.csp (accessed 2 May 2012).

Texas Education Agency (Division of Instructional Materials and Educational Technology). 2010. Textbook review and adoption process. Available at http://ritter.tea.state.tx.us/textbooks/adoptprocess/ (accessed 2 May 2012).

USGCRP (US Global Change Research Program). 2009. Climate literacy: The essential principles of climate science. Available at http://library.globalchange.gov/climate-literacy-the-essential-principles-of-climate-sciences-hi-resolution-booklet (accessed 2 May 2012).

Weatherley, J., Sumner, T., Khoo, M., Wright, M., and Hoffmann, M. 2002. Partnership reviewing: A cooperative approach for peer review of complex educational resources. *In* Proceedings of the 2nd ACM/IEEE-CS Joint Conference on Digital Libraries, July 13–17, New York: Association for Computing Machinery, p. 106–114.

Weller, A.C. 2000. Editorial peer review for electronic journals: Current issues and emerging models. *Journal of the American Society for Information Sciences*, 51:1328–1333.

Wise, S. 2010. Climate change in the classroom: Patterns, motivations, and barriers to instruction among Colorado science teachers. *Journal of Geoscience Education*, 58(5):297–309.