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Article

Building Student Proficiency with Scientific Literature Using the Zotero Reference Manager Platform

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While mastery of the scientific literature is a strongly desirable trait for undergraduate students, the sheer volume of the current literature has complicated the challenge of teaching scientific literacy. Part of the response to this ever-increasing volume of resources includes formal instruction in the use of reference manager software while engaging students with the primary literature. This article describes the incorporation of the reference manager program Zotero into a chemical literature course to facilitate the use of digital resources and to better enable them to use proper citation skills in their technical writing.

Keywords: Teaching and learning techniques methods and approaches, peer-reviewed writing assignments, skill development including cognitive skills, primary literature, scientific literacy, technical writing, information retrieval.

Within the broader category of communication skills, technical writing and reading of the literature continue to be particularly valued and emphasized in the Chemistry and Biochemistry curricula [1, 2]. As noted in 1991, even before the advent of the now-ubiquitous digital landscape, one of the major challenges of teaching these particular skills is the difficulty of keeping up with the massive nature of the scientific literature [3]. In the time since that earlier observation, the volume of available literature has increased almost exponentially as the internet, open-access journals, and publically accessible databases such as PubMed have come onto the scene.

To maximize the utility of the scientific literature, students must now be equipped with the skills to manage large volumes of literature information [4]. However, our students' ability to manage volumes of literature data must still serve as a compliment to their ability to discern significance and meaning from the data as well as using this data in the service of effective writing [5]. Developed by and for academic scholars, the reference manager program Zotero not only provides a platform that can be used to teach students how to manage voluminous citation data but also allows them to develop annotation skills for compiling comprehensive and meaningful citation entries. Armed with these fully formed citation entries, students can then draw upon their own discernment of the literature to further engage and develop their overall technical writing skills.

As described herein, Zotero was integrated into a literature course, taught as a part of ACS-certified programs in Biochemistry and Chemistry. By utilizing its simple browser interface, the software serves as an integral part of searching, selecting, and annotating literature information. Moreover, the ability of Zotero to work seamlessly with common word processor programs provided the means for students to directly organize and translate their understanding of the literature into a substantive, written literature summary.

ZOTERO

Zotero is a bibliographic management program developed at George Mason University [6]. It operates as an extension of the Firefox browser and integrates the full functionality of a reference manager directly into the browser interface. Zotero is available free-of-charge while providing the power and flexibility found in better-known, commercial products. Like Endnote©, it has the capacity to insert citations directly into Microsoft Word and OpenOffice, and has more than 1500 journal-specific bibliography formats available to users. Like NoodleBib©, it has the ability to incorporate flexible and comprehensive annotation of individual citation entries. By working within the Firefox environment, acquiring citations can be achieved by a single click of the mouse. This is accomplished using the encoded metatags that are incorporated within current websites for journal publishers and reference databases. From this metadata, Zotero is able to collect complete citation information, including full abstract text, and store it directly in a personalized library located on a local computer hard-drive, making it available for off-line use (Fig. 1). Most university library websites are likewise encoded so that any information regarding locally obtained books and materials can also be downloaded to an individual Zotero library.

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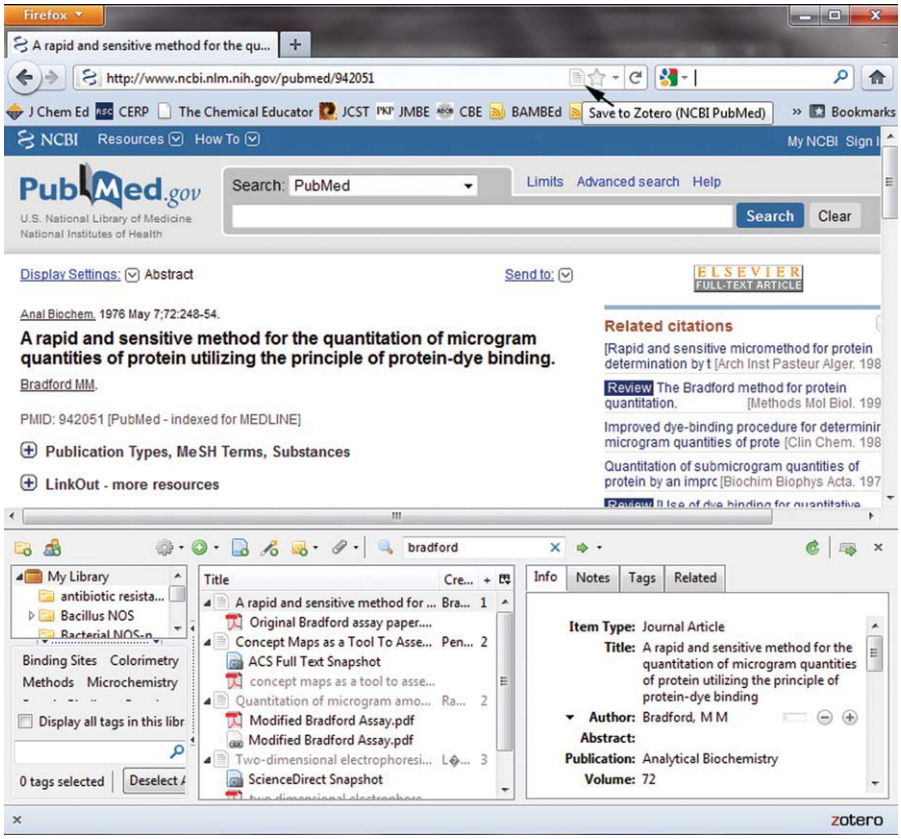

FIG. 1. **Screen capture of Firefox/Zotero interface**. The Zotero interface operates within the lower frame of the Firefox browser window. The PubMed entry shown here demonstrates the ability of Zotero to detect and extract citation data simply by clicking on the "Save to Zotero" icon located within the browser URL field. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Once collected, these data are fully searchable and can be organized, updated, and sorted at the discretion of the individual researcher. Each citation entry can be further supplemented with a number of attachments and tags, including a digital copy of the full journal article. Searching, annotation, and organizing can all be accomplished directly within the Firefox browser window. Software plug-ins are available for both Microsoft Word and OpenOffice which allow direct access to Zotero citation data within the word-processor environment. With this plug-in, researchers can search their personal Zotero database to select appropriate citations, whereas the add-on automatically inserts citation markers according to a selected publication format. A full bibliography can be generated by a single click of a mouse and the program will automatically reformat the document to accommodate any subsequent changes that are made to the document. Citations can be formatted according to an extensive list of journal citation styles that are available on the Zotero website.

Instructional Approach

Zotero was used in a Chemical Literature seminar course that met once weekly over the course of a 10-week quarter. Early in the quarter, students were introduced to library resources by a member of the library staff. Specifically, there was discussion of journal access via the library website and search databases such as Google Scholar, Scirus, Pub-Med, and SciFinder. Once students gained familiarity with the available (and appropriate) library and web-based resources, they were immediately engaged in the task of becoming familiar with the Zotero interface.

To begin their introduction, students were instructed on how to download and install both the Zotero add-on and the Microsoft Word plug-in. Students were then provided with a single journal article and instructed on how to access the article via the publisher's website and how to download the citation data into their Zotero libraries, as well as attaching a digital copy of the complete article in Adobe Acrobat pdf format. Once the initial data entry was in place, students were tasked with adding notes and keywords to the entry to create personalized annotations for the entry. A video tutorial covering all these topics is available on the Zotero website for additional student reference [7]. It was repeatedly emphasized that the three operating principles for constructing their annotations were: 1) why is this journal article of sufficient interest/importance to be included in your Zotero library, 2) what are the important and memorable facets of the cited work, and 3) how do I mark up this entry so that I can search and find this specific article after any number of weeks, months or years? Students were then instructed on how to generate a citation report, which is an html-formatted document that includes all of the citation data for a selected entry as well as any added personal annotations. The report page was then printed or emailed for evaluation by the instructor. This entry was evaluated on the basis of

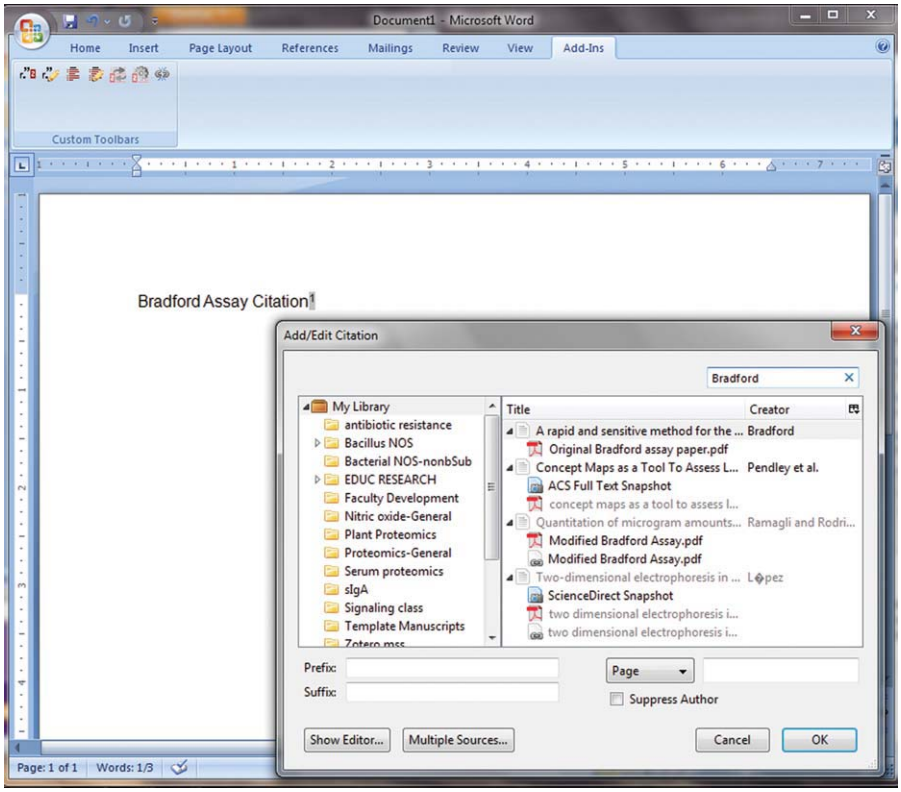

FIG. 2. **Screen capture of MS Word/Zotero interface**. Zotero citation data is directly accessible via the Add-Ins tab of the Word window. Individual citations can be found through the search function of the Zotero window, and citation markers within the Word document can be customized according to numerous journal formats. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

accuracy and, more importantly, the quality and depth of personalization.

This procedure for individual Zotero citation entries was then repeated by the students for a research journal article on a topic of their choosing. Review articles and monographs were excluded from this assignment so that students would have to construct their own interpretations regarding experimental data and not simply defer to the arguments or conclusions of an established review author. Again, students were tasked with developing personal annotations for their chosen articles. This process was then taken outside the class as students were assigned to annotate a total of three articles on the same topic. A single Zotero report was generated for a compilation of multiple entries and submitted for evaluation and grading.

Once multiple articles have been collected and annotated, students were then given an assignment to complete a short literature summary (maximum five pages) of their respective topic articles. Building upon the work that the students had done in their annotation exercises, they were first required to compose a bulleted outline developed directly from their personalized annotations. This step also provided an opportune moment to introduce the usage of the word-processor plug-in for Zotero. While working in the Microsoft Word environment, the plug-in allows the selection of a specific bibliographic format and can search for specific citation entries within the Zotero library (note: the Firefox browser must be open in order for the citation data to be accessible to Word). Once articles are selected, Zotero places an appropriate citation marker in the text (Fig. 2) and can generate a complete bibliography with a single mouse click. Upon completion of their notation outline, students can then move on toward the completion of their final document. Strictly speaking, this last phase of the assignment no longer requires the Zotero interface unless changes are made in the sequence or designation of citations within the text.

DISCUSSION

The nature of the scientific literature has changed dramatically over the course of the new millennium. The growth of the digital infrastructure has transformed access of materials from primarily bricks-and-mortar to a predominately digital medium [8]. To keep pace with rapidly changing nature of the scientific literature, the tools we employ to find, discern, and archive reference materials must be equal to the task at hand [9]. When measured against the vastness of the digital literature, the advantages of using reference management software seem obvious. For these reasons, it seems only logical that these digital tools need to become an integral part of how we define professional scientific literacy. While there have been several examples of materials that introduce students to the primary scientific, the use of reference manager software is only occasionally acknowledged and little attention has been given to working with the literature as a digital medium [10–14].

Beyond the simple need to keep pace with the ever-growing digital landscape, programs like Zotero can also help to strengthen the pedagogy used to teach and learn scientific literacy. Much of the current research in science

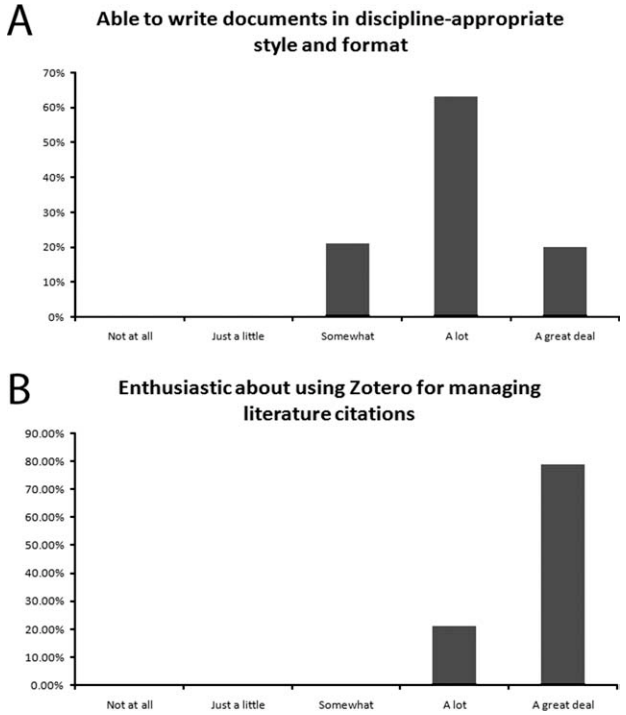

FIG. 3. **Histogram plots of student survey responses**. Survey responses were elicited based on a Likert scale of student opinions. Questions shown in each histogram window were predicated with the phrase "I am…". Responses relative to confidence in writing ability (Fig 3A) and enthusiasm for using Zotero (Fig 3B) both show highly positive student feedback correlating to a high sense of learning gains.

education is centered around constructivist learning theory, which proposes that knowledge is constructed in the mind of the learner and requires that the learner be actively engaged in the process of building his/her own knowledge [15]. In keeping with constructivist learning theory, students can engage in the process of developing their personalized keywords and annotations within the Zotero environment, which helps them to construct a better understanding of the literature being considered. This process of building a framework of knowledge around their chosen articles via keywords and reflections has been previously described as metacognitive monitoring [16, 17].

To assess the efficacy of using Zotero, a student survey was developed based on the Student Assessment of their Learning Gains survey tool [18]. Students' responses to the incorporation of Zotero into the class have been widely positive. When surveyed regarding the number of previous assignments that incorporated reference citations, over 80% of students responded that they had more than three prior occasions where such writing assignments had been completed, many of these during classes within their majors. Against this backdrop, the overwhelming student sentiment was that they wished that they had learned about Zotero earlier in their undergraduate careers. Many students commented on the pure tedium of formatting bibliographic entries by hand and how using Zotero might actually serve to improve their attribution skills by eliminating that tedium. As shown in Figure 3, students are not only enthusiastic about using Zotero but also appear to have an equally strong sense of their ability to write in a discipline-specific manner. Similar results are seen when students were asked about their ability to work with digital literature resources.

In summary, the incorporation of Zotero in the Chemical Literature curriculum has yielded a three-fold benefit for students. First, the use of Zotero allows students to create personalized citation libraries that are consistent with professional expectations and appropriate for the ever-changing digital landscape. Second, the development of pertinent keywords and notes within the Zotero environment helps students to build and strengthen their knowledge of individual citations in a more constructivist fashion, which leads to more meaningful understanding of the contents of each annotated article. Third, the elimination of tedious hand formatting of bibliographic entries encourages more rigorous attribution and raises students' enthusiasm for proper uses of literature citations.

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