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TEACHING EVIDENCE-BASED INNOVATION (EBI) AS A TRANS-DISCIPLINARY PROFESSIONAL SKILL IN AN UNDERGRADUATE BIOLOGY WRITING WORKSHOP

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A strategy for using writing in the college classroom to facilitate innovative thinking and entrepreneurship among biology students is described. The intellectual advantages of a science curriculum are employed as a platform for helping students use writing as a tool to collect, evaluate, and propose innovative ideas. Information literacy is emphasized as a basic, foundational skill for science innovation. Various strategies for learning effective science writing are then reviewed. Included is a progression from writing an essay, to preparing a review article, to writing an original research proposal. A highly-structured peer editing process is then explained. The extension of science innovation to entrepreneurship is diagrammed in order to represent the continuum that extends from the conception of novel ideas to their introduction to a larger audience.

Keywords: Innovation, Information literacy, Writing for innovation, Teaching innovation, Evidence-Based Innovation, Undergraduate science writing.

"In conversation you can get away with a lot of nonsense, even without knowing it. But when it comes down to writing, your foolishness quickly becomes apparent." (Iacocca & Novak, 1984)

Introduction

Productivity gains from computerization, digital communications, and the globalization of labor forces and transportation networks continue to stress national economies. "Innovation" is frequently referred to as the most promising panacea for stressed economies (Miller, Klokgieters, Brankovic, & Duppen, 2012). By "innovation," policy makers usually mean *the introduction of novel ideas, methods, processes, or equipment to various production/service aspects of an economy*. Of special interest to policy makers ranging from local to national levels are higher education systems such as community colleges and public universities. Those institutions are often publicized as sources of innovation for economic development (e.g., Figure 1). The topic of how to design curricula and courses to effectively teach innovation has, however, been largely ignored.

Figure 1. Highway billboard advertising a publicly supported research university (Indiana University). It is generally expected that college students, if "properly" educated, will drive innovation.

Investment in higher education in the USA and many other economically developed countries is often skewed towards science and technology studies as well as faculty research areas. That is, faculty appointments, as well as resources such as laboratories, classrooms, and equipment, are frequently disproportionately allocated to science departments. To a large extent, that is because science, especially biology, is generally expected to generate the largest long-term gains in the types of innovation that will enhance economic development (Stephan, 2012). Several factors have led to this emphasis: Aging/expanding populations require advanced health care (including high-tech drugs, therapies, and surgeries); agricultural productivity needs to be strengthened to support an increasing global population; natural resource (e.g., water) depletion calls for novel conservation methods; etc.

University science research laboratories comprised of graduate students, research technicians, and faculty do, of course, provide important contributions towards understanding and creating innovative ways to deal with some of those future needs. In order to foster the development of a more complete and effective innovation culture, it is, however, necessary for universities to help the much larger number of undergraduate science students prepare for an innovative economy.

Considering the urgent need for increased innovation in life sciences research, it is encouraging to note that there are an estimated 86,000 biology majors graduating from US colleges each year (Drew, 2011). Some of those majors will, of course, go on to work as professional researchers or practitioners in science or medicine. Most will, however, enter the general (non-science related) workforce where they will be competing for the same employment opportunities as their peers from other, non science-related areas of university study. A large percentage of those job openings—at present—favors graduates who are most likely to have a creative mindset and skills that favor innovative thinking.

There are few more appropriate or authentic places to develop and implement practices for teaching the innovative mindset than the undergraduate science classroom. Key findings from a survey conducted by the Association of American Colleges and Universities (Association of American Colleges & Universities, 2013) support this assertion. When asked about their priorities for learning and student success, 80% of businesses and non-profits recommended that "**every college student should acquire broad knowledge in the liberal arts and sciences**". Ninety five percent **said they** "prioritize hiring college graduates with skills that will help them contribute to **innovation in the workplace**." Also, in a Forbes list of "10 Skills That Will Get You Hired in 2013" (Casserly, 2012), the top 3 skills are (in order) "critical thinking," "complex problem solving," and "judgment and decision-making," all essential to the innovative mindset.

Preparation of university students for participation in an innovation economy is, of course, a necessary goal. Simple explanations in the classroom of terms such as "innovation," "entrepreneurship," etc., although necessary are–-alone—probably not sufficient to motivate students to seriously consider engaging in a novel endeavor. In order for students to consider themselves potentially successful for contributing to change, they need to understand that innovation entails more than just a personal imagining of original or creative thoughts. Thus, the modern liberal arts classroom needs to address multiple contributing factors in order to foster the development of the innovative mindset. Herein, an approach called Evidence-Based Innovation (EBI) is offered to serve as a framework for teaching those important skills including "ways of thinking". EBI can be best described by the following sequence of logic:

1. **Innovation** promotes progress in many scientific and intellectual discovery endeavors including economic growth, health and social services, environmental sustainability, etc.
2. Innovation is grounded in, informed by, justified with, and made broadly acceptable by the **Evidence** that provides its research/development platforms.
3. Finding and using evidence requires **Information Literacy** skills**.** In addition, communicating new evidence requires **Writing** skills. Both are fundamental prerequisites for participating in "information-age" activities. Those activities include entrepreneurship, as will be described below (see Figure 7).

As illustrated in Figure 2, information literacy and writing provide a starting point for engagement with evidence, and its evaluation serves as a starting point for innovation. That is, the quality, reliability, and importance of evidence serves as a primer for employing an innovative mindset.

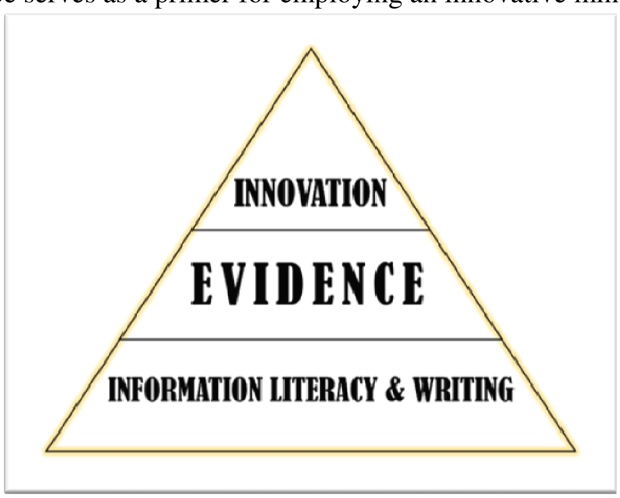


Figure 2. An EBI pyramid is built on a platform of information literacy/and writing skills. It provides a conceptual approach to the development of novel ideas. This pyramid encourages curiosity and contemplation (e.g., writing) as starting points for innovative thinking.

This report builds on a previous publication by the authors that described approaches used in their upper-level undergraduate class, L322 Writing Workshop in the Logic and Rhetoric of Molecular Biology (Malacinski & Winterman, 2012). While the present report focuses on the approaches used by the authors to teach EBI in the context of a writing workshop for undergraduate biology students, these concepts and practices are trans-disciplinary in nature and could be employed in classes across the curricula of liberal arts and professional schools.

Biology Students as Candidates for an EBI Learning Experience

Biology students are well-prepared for participating in an innovation culture. Traditional biology curricula provide a wide range of study areas that offer a foundation for knowledge building and problem solving. Table I lists several of those activities. In each case, "evidence" is emphasized as providing the basis for building the knowledge base that advances science and offers opportunities for translation of those advances into innovative ideas. Both reductionist (e.g., analyses of gene mutations) as well as holistic (e.g., field studies) aspects are usually included. Such diversity of subject matter prepares students to employ—simultaneously—multiple learning/imaginative tools for problem solving. That strategy has been referred to as "transformational thinking" (Root-Bernstein & Root-Bernstein, 1999). It provides an excellent platform for developing an innovative mindset.

Skill set	**Subjects and activities that contribute to EBI**
Design of experiments	*Laboratory experiences*
Data analysis	*Attention to detail by preparing graphs/extrapolations*
Dealing with complexity	*Intermediary metabolism (e.g., glycolysis)*
Understanding networks	*Ecosystems (e.g., food chains)*
Acknowledging mechanisms of change	*Mutations generate evolutionary diversity*
Engaging in field studies	*Effects of climate change on local flora*
Predicting human behavior	*Observing/analyzing primate behavior*

Table I. Emphasis on classroom (and laboratory) evaluation of the "evidence" gained either through direct observation or experimental analysis provides biology students with practical skill sets.

"If you want to train innovative and successful scientists, there isn't any doubt that you want to teach them to love and cherish writing." (Michele and Robert Root-Bernstein, 1999)

Writing as a Foundation for EBI Learning Experiences

The Figure 2 skill sets might qualify biology students in some ways as ideal candidates for EBI. However, the essential skills of writing and information literacy are unfortunately often not consistently taught in science courses. Traditionally, undergraduate science courses have focused on the "transfer-of-information" mode of learning where they are "told about science and asked to remember facts." (Alberts, 2009; Handelsman et al., 2004). In that way, traditional biology courses represent “history courses.” That is, the details of past discoveries are reviewed, with future directions given passing mention. Rote memorization—perfected by most students in high school—continues to be the main learning skill for earning high grades in undergraduate biology courses. Yet memorization alone cannot produce disciplinary expertise.

Writing, when taught as a process-based activity that culminates in a written representation of one’s thinking, provides an authentic and active way of learning disciplinary content. As well, authentic writing requires individuals to translate and synthesize their own thoughts and those of others into an original product that is both significant and interesting. With this approach, writing as a learning activity transcends the consumption and regurgitation of information that frequently occurs in many undergraduate writing exercises. Indeed, writing that truly facilitates EBI is characterized not only by good mechanics (grammar, vocabulary, prose, etc.) but also by the student’s ability to think deeply and critically about the subject matter and to conceive of novel perspectives, approaches, and solutions.

Information Literacy as a Foundation for EBI Learning Experiences

Information literacy refers to an individual’s ability to access, evaluate, and effectively use information. This skill set is most readily acquired in the context of a discipline. In L322, teaching information literacy focuses on the nature and structure of biological information based on published literature that represents what is “known” and “unknown.” The different types of literature reflect how ideas are transmitted from the scientist to various audiences. Viewed this way, information literacy represents a skill that extends beyond simple knowledge of information tools to include expert ways of communicating and thinking in biology.

When combined, information literacy and writing provide the necessary foundations for students to engage with evidence. In a highly-cited report on the subject of people as “intuitive scientists,” Kuhn asserted that “…skills in coordinating theories and evidence arguably are the most central, essential, and general skills that define scientific thinking” (Kuhn, 1989). In the context of undergraduate education, *what constitutes evidence* should include not only what one might *personally* observe in the field or laboratory but also what *others* have observed and reported.

Furthermore, it is generally recognized that truly objective evaluation of evidence is essential to scientific thinking. In describing the so-called “nature of science”, Lederman discussed the “tentativeness” of science by pointing out that “scientific knowledge is never absolute or certain” (Lederman, 1998). Thus, scientific knowledge should not be viewed as simply the accumulation of *proven facts.* Rather, it is best understood as an ongoing “conversation” about the quality of *evidence*. Writing and information literacy empower students to become participants in, not just observers of, that conversation about evidence. That is one of the underlying principles the authors employed in the development of approaches to teach EBI in L322 (described below).

Approach #1: Active Learning Strategies

Designed as a writing “workshop”, L322 engages students in a variety of class activities. They are encouraged to *learn by doing* in a number of ways. For example, as a prelude for each major writing assignment (see Table II), the class meets in a computer-equipped classroom (Figure 3). There, students research background information with the professors nearby for consultation on search strategies, literature evaluation, and topic development. Only when students have developed these skills are they able to prepare a knowledge base for engaging in both the analyses and critical-thinking modes that are prerequisites for innovation. The process of evaluating background information, frequently modeled by the professors in the classroom on a large screen monitor, provides a means for directing students away from the "information survey" mode of learning. Instead, curiosity-driven mindsets are encouraged. Interestingly, students appreciate the opportunity to perform this intellectually challenging work during class time together with professors (rather than, for example, alone in their preferred evening study locations).

Figure 3. Students engaged in active learning exercises in a computer-equipped classroom. The instructors consult with students individually on information-gathering and evaluation, and demonstrate for the group literature search techniques on a large projection screen.

Approach #2: Learning Progressions

Individual writing assignments in L322 emphasize "process" over "product." That is, students prepare outlines, literature searches, first drafts, etc. that are examined by both peers and the professors along the way towards developing their final report. Likewise, the design of L322 is based on the concept of learning progressions. Assignments are iterative and increase with complexity and sophistication to provide an opportunity to measure EBI progress. Though most of the students are seniors, instructors assume that some students enroll in the class with little or no prior experience with either information literacy or academic writing. Indeed, few students actually report having had previous experience with technical or scientific writing, except for laboratory reports. The chronological sequence of the learning progression, along with the ultimate goal of EBI, is described in Table II.

Product	**Audience**	**Course (student) learning goals**
Procrastination Essay	Peers (classmates)	Become acquainted with the **writing process** and reflect on their personal experience with procrastination as well as tools for overcoming it; professors get acquainted with students' basic **writing skills.**
Book Chapter	Biology Graduate Students	Become acquainted with and learning how to find a **variety of information sources** in order to write an overview of a molecular biology topic.
Current Topic Essay	Biology Graduate Students	Evaluate and use a few **authoritative sources** to synthesize own ideas as well as those of others' to gain practice developing **perspectives.**
Review Article	Experts in Field	Perform **comprehensive literature searches** to identify the most current and important sources in a given field. Read, evaluate, and use select sources in order to develop **expert-level perspectives.**
Research Proposal	Experts in Field	Perform comprehensive literature searches to identify **unknowns, unsolved problems, or gaps in knowledge**. Use information from primary literature as **evidence** to justify an **innovative** approach.

Table II. Each writing exercise (product) in the sequence provides a foundation for achievement in the next exercise.

Approach #3: Authenticity and Modeling

The assignments described in Table II are authentic writing and thinking exercises that teach a skillset and mindset necessary for engaging in the professional and scientific worlds. L322 does not include writing assignments called "term paper" or "final project," because those are, at least in name, inauthentic tasks. The instructors of L322 strive toward authenticity in other ways, as described below.

Modeling Authentic Professional Information Behaviors

L322 is co-taught by a molecular biologist (GMM) and a science librarian (BW). The librarian models professional information-collecting methods in the classroom (Figure 3) as well as during individual consultations with students. This learning exercise involves demonstrating search strategies, selection of databases and tools, retrieving and using specific types of documents, and proper citation of sources. Once information has been collected, most students need guidance on how to extract relevant information from those primary sources. Typically, students have had little experience reading scientific journal articles. With a journal article projected on a large screen, the molecular biology instructor occasionally models a professional approach to actually examining the article. Explicit mention is made of specific sections of the report (e.g., Introduction, Discussion, etc.) as well as the importance of illustrations and tables of data. How a professional achieves overall comprehension of the article is furthermore described. Curiously, students are often surprised as they watch the manner in which seemingly difficult and opaque prose is reviewed. For example, a professional scientist focuses mostly on the graphical (visual) representations of data, then reviews the text when necessary for further comprehension!

Review of Current and Past Molecular Biology Innovations and Innovators

By explaining personal associations and experiences with famous biology innovations, the professors stimulate undergraduate students to generate their own novel ideas. That is, the professors explain specific background and historical notes about famous innovators. For example, the instructors review and discuss news and perspectives about discoveries made by Nobel Laureates. Students are generally very enthusiastic about becoming exposed to such information. Also, a representative class is occasionally begun with an image projected on a large screen of a historical document or photo related to accomplished biologists from Indiana University's past (e.g., Tracy Sonneborn, Hermann Muller, and Alfred Kinsey). These artifacts, obtained from the Indiana University Archives or the special collections of the I.U. Lilly Library, might include correspondence between scientists and administrators, photographs from laboratories and classrooms, or written works such as essays, proposals, and reports. The display of these materials is often accompanied by rich commentary and historical perspective from the instructors. The aim is to instill a sense of academic heritage and empowerment in students, while at the same time providing real-life (insider's view) examples of important local innovations. This helps undergraduate students realize that they are participating in an endeavor at a time and in a place that has been universally acknowledged for its innovative research.

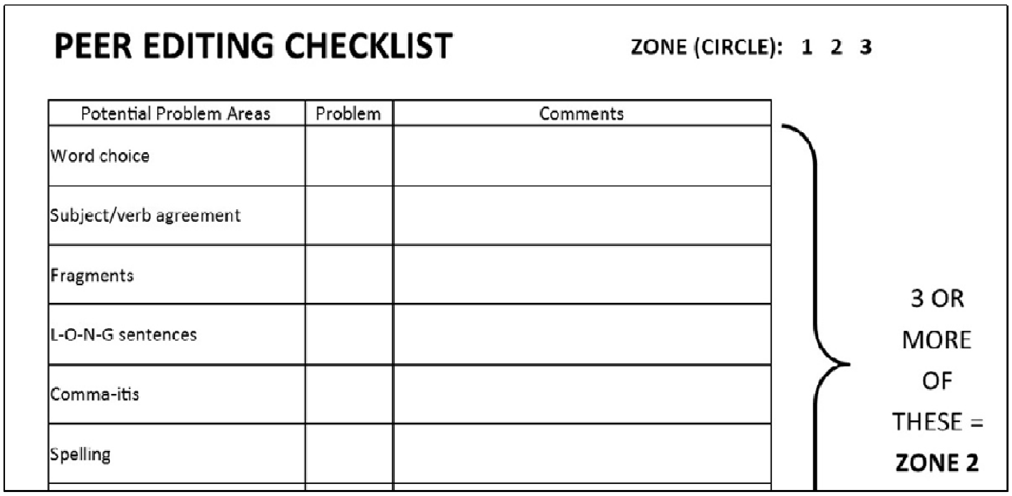
Approach #4: Learning from Peers

The activities and lessons listed in Table I that comprise the typical biology course provide a foundation for enhancing forward-looking and predictive thought processes. Developing procedures for transforming these thought processes into an innovative mindset through writing is, of course, the primary goal of L322 and the teaching of EBI. Peer or group learning has been demonstrated to enhance the level of academic achievement for science students (Gaudet, Ramer, Nakonechny, Cragg, & Ramer, 2010), and evidence supports the use of peer learning in scientific writing, too (Senkevitch, Smith, Marbach-Ad, & Song, 2011). However, most writing in science courses appears to revolve around the solitary activity of writing laboratory reports. Much of the work in L322 has therefore been formatted to involve collaborative learning in one way or another. Also, with authenticity in mind, the quality of an innovative idea in the sciences (and elsewhere) is ultimately judged by fellow experts. One of the best examples for modeling critical review of the reports listed in Table II is the in-class peer editing that takes place for each of those major writing assignments.

Zone Peer Editing

Innovative thoughts can only be conveyed through clear expression of those thoughts, and in the context of science that expression occurs most often in writing. Major funding agencies such as the U.S. NIH and NSF request that a proposal address various guidelines. Included as indispensable and standard criteria for what is deemed "fundable" innovation are characteristics such as novelty, significance, and feasibility. It is assumed that the applicant will clearly address those features in a way that is easily understood not only by a specialist reviewer, but also by non-expert professionals (e.g., legislative policy makers). According to the L322 model, writing is a representation of thinking. While thinking alone might be clear, and might even meet the criteria of a major funding agency, effectively transmitting those clear thoughts to others via writing also requires proficiency with simple writing mechanics. Unfortunately, students in L322 often struggle with vocabulary choices, grammar problems, and sentence structures. Thus, the instructors' ability to extract the greater meaning and thoughts behind a student's written product is often challenged. To minimize this obstacle, and to promote a common awareness of peer work and achievement, the instructors have developed the following method for peer editing of written works.

Step #1: Prior to the due date for the major writing assignments (see Table II) students are required to bring 2-3 unsigned copies of their most recent drafts to the classroom. Those anonymous copies are then randomly distributed among students along with an editing checklist (Figure 4) to guide student editing.


PEER EDITING CHECKLIST ZONE (CIRCLE): 1 2 3

Potential Problem Areas	Problem	Comments
Word choice		
Subject/verb agreement		
Fragments		
L-O-N-G sentences		
Comma-itis		
Spelling		

3 OR MORE OF THESE = **ZONE 2**

Figure 4. Partial check list includes several criteria that address mechanics, structure, clarity, and logic of an early draft of the assignments listed in Table II.

Step #2: The classroom is organized into a system of zones (Figure 5). Most students are assigned to Zone 1 and perform most of the routine editing (spelling, grammar, etc.). If a certain number of criteria on the checklist are met, the draft is passed on to Zone 2 which is usually composed of 3 students who have proved themselves to be especially effective writers and editors. Finally, if major concerns about content, conclusions, etc., are recognized, the draft is sent to Zone 3 where professors can comment on a "draft in need of help."

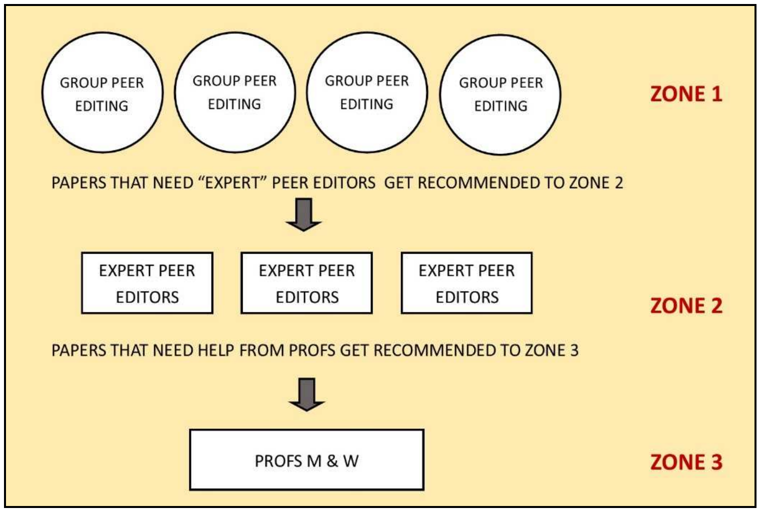


Figure 5. Illustration of Zone Peer Editing. By the end of the semester most drafts remain in Zone 1, indicating that students were overcoming the simple careless mistakes often found in earlier writing assignments.

Step #3: By the end of the class period, most students will have had their paper anonymously edited by 3 different peers in Zone 1. Students can then examine and evaluate the editors' comments and determine what revisions, if any, need to be made.

Figure 6. Collaborative peer editing session. Class is comprised of 20-25 students (mostly college seniors). They appear to be fully engaged. Note that one student is using a Thesaurus (book) in order to recommend a "more appropriate" word. Subsequent feedback from a written questionnaire to the whole class revealed that students found collaborative editing enormously useful.

"The world is moving so fast these days that the man who says it can't be done is generally interrupted by someone doing it."

(Elbert Hubbard, c.1913)

Approach #5: Student Reflections on the Innovative Mindset

Students are encouraged to focus on thinking creatively as they develop research proposals that represent breakthrough or transformative discoveries. The distinction between innovation and incremental types of change is emphasized. The following general characteristics of innovative scientists are reviewed in the classroom: They are comfortable with ambiguity; they act without needing definitive "proof" as a starting point; they are not constrained by historical antecedents; they ask "what if?;" they search for meaning; and they are prepared to accept failure.

In addition to writing about innovative perspectives and approaches through reviews and research proposals, L322 students are required to write about the innovative mindset itself.

(Figure 7). While the professors discuss in class the thought processes that comprise this mindset, students benefit from this exploratory and reflective exercise partly because it allows them to define the concept in their own words.

Assignment: Prepare a one page (single-spaced) essay on the *innovative mindset.*

a. Include a 2-3 sentence explanation of the term *innovative mindset*.

b. Include 3 examples of innovative research/development projects that will likely benefit from participation of biology graduates.

Figure 7. Students offer a variety of perspectives when requested to explain and define the concept of the innovative mindset.

"*One overriding challenge is now coming to the fore in public consciousness: We need to reinvent just about everything." (Markham, 2013)*

The Trans-Disciplinary Nature of EBI

Initially, this writing project was designed for biology undergraduates. Nevertheless, the conceptual foundation of the EBI endeavor and its related thought processes are applicable to many liberal arts courses as well as professional schools. The librarian author (BW) serves as a consultant on information literacy assignment design and assessment, and advises professors of undergraduate classes in multiple disciplines. Consultation of this nature frequently involves a discussion of the so-called "product of the program". That is, a written articulation of what students should be able to do with both their information and communication skills when they graduate. While there are some subtle differences from one program to another, most desire a "product" which is similar to the goals of the EBI-based writing projects in L322. Specifically, professors have commented that they want their students to be able to explain and justify their novel perspectives or thought processes using the literature, logic, and evidence of their discipline. Whether studio art students writing an artist's statement or biology majors proposing a research project, the goals are similar. The practices and materials developed in L322 have therefore been adapted for use in many classes at Indiana University, including subject areas as diverse as chemistry, business, nursing, and art history. Despite obvious differences among disciplines and programs, EBI appears to have the potential to serve as a broad unifying principle for developing effective approaches to the undergraduate learning experience.

Innovation, Entrepreneurship, and Risk

The concept of innovation is widely offered as a solution to national unemployment and stagnant economic growth. Although innovation is necessary, it alone is not sufficient to drive prosperity. Often, innovation leads to job redundancies as labor productivity increases**.** The classic example—in the USA—is the innovative machines that led, post WWII, to enormous increases in agricultural productivity, followed by decreased farm employment, consolidation of the industry and—in many cases—desired reductions in food costs**.**

In order for innovation to have the desired effect of increasing employment opportunities, new products or services need to find their way to the marketplace in such a way that they supplement rather than simply displace preexisting employment. That is, entrepreneurship needs to follow innovation.

Fortunately, many of the features of the innovative mindset are common to the early stages of the process of entrepreneurship (Figure 8). As students learn to acquire knowledge on their own and critically analyze it, it can be expected that their self-confidence will be enhanced. As a consequence they are likely to become less risk-adverse and thereby willing to pursue innovative ideas. Risk-taking is, however, a concept that frequently is avoided, both by young students eager to earn high academic honors as well as faculty who are deeply invested in a traditional field of study. The EBI classroom experience might therefore be expanded to include group discussions about risk-taking and its consequences. Questions could be posed such as: *What is the most significant risk you have taken in your life? How do you cope with uncertainty? How do you feel about failure? What are typical consequences of failure?* In contrast, questions such as the following might also be posed: *What are the payoffs from success? How can the social consequences of failure be reversed?* Above all, discussion of how entrepreneurs make sense out of failure, and how they learn from it should provide a constructive outcome to this difficult topic (Ucbasaran, Shepherd, Lockett, & Lyon, 2013; Kuyatt, 2011). Indeed, there is a conference called FailCon (http://thefailcon.com) where entrepreneurs gather to share and learn from their failed start-ups. Their mantra is "stop being afraid of failure and start embracing it!"

Coincidently, writing assignments in L322 offer students some experience with risk-taking. They are asked to present unique perspectives and propose novel approaches to very complex topics. Most have never experienced those demands in the classroom or elsewhere, since many undergraduate students assiduously avoid high-risk endeavors. The extensive (anonymous) peer editing process described above (see Figure 6) does, however, provide students with a sampling of sharp criticisms from their peers. Thus, they are presented with an opportunity to experience a mild dose of failure (e.g., in their attempts to devise a novel idea, to explain their idea, or to use both logic and rhetoric to present their idea) in this writing workshop.

He who risks and fails can be forgiven. He who never risks and never fails is a failure in his whole being." *(Paul Tillich, Theologian and Philosopher, b. 1886)*

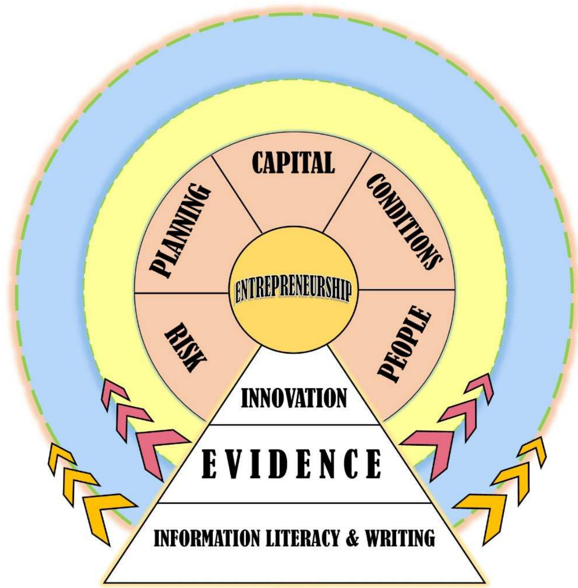


Figure 8. The EBI pyramid (see Figure 2) contributes to the ultimate goal of entrepreneurship. Innovation, combined with other factors such as planning (strategic, business, etc.) and conditions (social, economic, technological, geopolitical, etc.), provides a foundation for entrepreneurial endeavors.

"I do not want to spend my career just 'filling in the blanks'.

I want to do something new!"

(Ashley Williams, undergraduate student at Indiana University)

Progression beyond Innovation to Entrepreneurship

The conceptual endpoint of the EBI endeavors described herein is, of course, the dissemination of innovative ideas. That usually requires entrepreneurship, in one form or another (e.g., bringing a new product or service to market, revising the manner in which a novel academic discipline is organized, or enhancement of an administrative function in either government or private sector endeavors.

In the course described in this report, various aspects of innovation are built into the agendae of the major writing assignments. The innovative mindset has been described by various academic scholars to represent *the ability to sense, act, and mobilize under uncertain conditions.* An entrepreneur is able to think beyond (or re-organize) existing knowledge structures and heuristics. Thus, as described by Haynie, Shepherd, Mosakowski, & Earley (2010) "adaptable cognitions in the face of novel and uncertain decision contexts are employed by the entrepreneur."

In the context of biology courses, after routine descriptions are completed in the classroom, a discussion re. “In what way should this biological phenomenon be viewed next?” can provide an entree for explaining the relationships between EBI, innovation, and entrepreneurship. Such an approach to leveraging university research discoveries into marketable products has been hugely successful for pharmaceutical companies (Stephan, 2012). Several very recent examples are also included in the Top 10 Innovations 2013 (http://www.the-scientist.com/?articles.view/articleNo/38394/title/Top-10-Innovations-2013/).

Other undergraduate academic disciplines including economics (e.g., Piketty, 2014), political science, business/finance, and sociology—to mention a few—should be considered candidates for employing the EBI model in the classroom. The resulting entrepreneurship need not be directly linked to commerce. Rather, the EBI model might provide novel ideas for re-organizing social structures, political systems, etc. (e.g., http://www.slideshare.net/curtistim/social-entrepreneurship-education-outside-the-business-school).

Critique of the EBI Model Described Herein

Science students bring to the EBI model a variety of strengths and advantages. For example, university students are generally enthusiastic about enrolling in a biology curriculum in part because biology research is in the midst of a so-called “golden era.” That era began with the elucidation of the structural features of DNA and the subsequent sequencing of the human genome. Presently, excitement abounds regarding prospects for drug discovery, regenerative biology (e.g., embryonic stem cells), personal DNA sequence information (i.e., gene typing), etc.

In addition, large numbers of undergraduates who aspire to careers in medicine and other health science endeavors also major in biology, or other science/science related courses (including chemistry, psychology, etc.). Those concerned about and wishing to study natural resource depletion (e.g., water), climate change, and environmental pollution are also drawn to biology.

As revealed in Table I, biology students receive training in many skill sets. Special focus is placed on experimentally derived “evidence” that provides a platform for innovative thinking. Indeed, as explained above, enhancement of those innovative thinking skills can serve as a stepping stone to entrepreneurship (see Figure 8). A variety of limitations nevertheless characterizes endeavors of the type described herein.

- Science (and mathematics) students generally prefer to avoid reading tasks. For example, they show little interest in learning biology through the lens of history. Instead, they prefer to engage in physically active pursuits, such as working at the laboratory bench, or collecting data from field studies. Thus, they usually show little intrinsic interest in reading and writing exercises that emphasize verbal reasoning. Dynamic features of scholarship such as active learning that involve collecting and analyzing data provide a much greater attraction for them. Graphs, diagrams, electron micrographs, etc., generate a special appeal to biology students. That is, illustrations play to their innate attraction to visual images. Indeed, courses that emphasize quantitative or structural aspects of a phenomenon attract more of their attention, at the expense of reading and writing courses. It is therefore suggested that when possible EBI exercises be built around “evidence” that is exhibited in the form of a table, graph, or illustration.

- Due to that inherent aversion towards formal writing exhibited by science students, the in-class peer-editing exercises described above in Figures 4 and 6 need to be proctored by a professor to insure that the quality of student editing reflects the professional standards on which this writing program is based. Even self-editing tactics such as reading out loud have sometimes proven ineffective among many science students. They simply are not diligent at recognizing typographical errors and missing words in their own writing. And, of course, their vocabulary is not highly developed due to their reading deficiencies. In fact, it is possible that the greatest benefit of peer editing to the students of L322 is not the feedback they receive from their peers, but the opportunity to observe strengths and weaknesses in their peers' work that might inform their own development as writers.

- L322 is a resource-intensive course. The grading process is very time-consuming. For most of the major assignments students choose their own topic. Thus, the professor needs to shift among approximately 20 different topics during the course of the several days required to read carefully and comment in detail on each different report. Likewise, because each writing assignment is completed in steps, and each step entails feedback from instructors, time spent giving individual attention to students is a significant commitment, even with 2 instructors. In addition, the use of a computer laboratory (e.g., Figure 3) with a large projection screen is likely not available at all colleges and universities.

Nevertheless, various aspects of the EBI approach very likely can be adapted to many upper-level college and research university courses.

Discussion

Development of "innovative thinking" in the typical college biology classroom is given low priority by faculty, compared to the "information transfer mode" of teaching. The EBI model presented herein therefore represents a progressive approach to learning science. Rather than explaining those important discoveries--detail by detail--in the lecture hall this approach emphasizes using a review of those discoveries as a starting point for "what comes next?"

Individual creativity and innovation are, however, normally considered difficult to teach and learn in the typical science classroom. Courses that propose to teach innovation do exist, but the practical difficulties associated with promoting innovation abound (Horth & Vehar, 2014). Nevertheless, it is generally recognized that innovation most effectively emerges from small cooperative groups (e.g., the peer review activities mentioned above). Thus, the EBI approach described herein attempts to provide students with the requisite "first encounter" with a model for generating creative and innovative approaches to evaluating ideas and novel speculations.

In the future, teaching and learning EBI might be improved by integrating writing and information literacy exercises earlier in an undergraduate program to acquaint students at the beginning of their studies with the use of science literature for writing. L322 students are mostly seniors with little preparation for using literature or producing written work, so, like other professors of upper-level courses, the instructors are left with the burden of teaching what might be considered remedial skills. Providing a sequential platform for EBI in undergraduate curricula would offer students the opportunity to develop this mindset over the course of several years and in multiple contexts.

The first author (B.W.) has, in fact, worked extensively in the area of program-wide integration of EBI, both designing assignments at the course level and establishing a "blueprint" for the process of curricular integration and assessment (Winterman, 2014). However, adoption of these practices and materials in programs has been somewhat limited, partly because of the limitations mentioned above regarding time-investment from the instructors. Many courses at the freshman and sophomore level often enroll 150 students or more. Support from teaching assistants also varies. Finally, many instructors find it challenging to sacrifice information content in order to dedicate class time for writing and information literacy exercises. The professors who have done so in large classes were successful because the exercises were integrated into course content, the assignments were brief or done in steps, and there was support from teaching assistants (Kehoe, 2014; Montooth, 2014; Reck, 2014).

One approach that might further facilitate integration and help generate a classroom culture of innovative thinking has been described by an instructor in South Korea (Zastrow, 2014). The typical science lecture is replaced by online-reading homework. Then the readings are discussed in small groups in the classroom under the supervision of an instructor. As explained by Zastrow, "most of the learning happens among the students themselves". If that approach were supplemented with EBI exercises and adopted by a variety of courses in an undergraduate curriculum, perhaps an even more successful outcome than described herein would be achieved.

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