AC 2008-2268: STUDENT WRITING: AN ACTIVE LEARNING TOOL IN PHYSICS AND ENGINEERING EDUCATION

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Student Writing:
An Active Learning Tool in Physics and Engineering Education

ABSTRACT

The educational benefits of adapting a writing approach in the classroom have been widely documented. Writing can serve as an effective tool to improve the quality of teaching through the promotion of deeper and more meaningful student learning. This paper will explore strategies in which writing can be used to enhance student understanding within introductory physics and engineering curricula. The prominent strategy to be described involves having students research, write, and present a paper at a formal class "conference" held at the end of the term. Throughout this process, students are exposed to all aspects of preparing a professional conference paper including the submission of an abstract, preparation of a paper for review, participation in a rigorous peer review, and presentation of their final paper at the conference. One focus of this paper will be to highlight each of the aspects of the paper writing process, placing particular emphasis on the significance of the peer review process. A discussion involving the rubrics developed and used during the peer review process will be shared. Highlights of the writing curriculum developed in both the physics and the engineering classrooms will be offered. Strategies for effectively dealing with large class sizes will also be presented. It is anticipated that the writing strategies to be described will provide educators within the domain of STEM education with viable tools to assist them in developing and/or enhancing the use of writing within their own classrooms.

I. INTRODUCTION

The primary purpose of teaching is to facilitate student learning. Traditional teaching methodologies have been shown to put students in a role of passive rather than active learning [1]. In addition, traditional instructional methods have also been shown to be very inadequate in terms of the promotion of deep learning and long-term retention of important concepts. Students in traditional classrooms acquire most of their "knowledge" through classroom lectures and textbook reading. A troubling fact is, after instruction, students often emerge from our classes with serious misconceptions [2] - [6].

A significant body of educational research supports the fact that students must be functionally active to learn [7] - [9]. Furthermore, Koballa, Kemp, and Evans [10] note that "ALL students must become scientifically literate if they are to function in tomorrow's society" (p. 27). Scientific literacy is of critical importance for all students at all educational levels.

The *National Science Education Standards* [11] strongly emphasize that inquiry-based techniques should form the core of what it means to learn and do science. Edwards [12] suggests that the publication of the *National Science Education Standards* offer reason to be optimistic that inquiry-based learning will become a central part of science education. Inquiry-based learning strategies originate from the constructivist model and encourage an active, hands-on approach to learning [13] - [14]. The constructivist approach embraces the idea that knowledge

cannot be acquired passively [15]. In addition, the National Science Foundation currently has several programs that promote the integration of standards- and inquiry-based SMET educational materials and instructional strategies from elementary through graduate school [16].

In recent years, a number of writing techniques have evolved that make use of various writing-to-learn strategies within the domains of engineering, mathematics, and the sciences [17] - [25]. The use of writing in introductory classes for non-majors may be an effective vehicle for allowing students to enhance their critical thinking and problem-solving skills. Writing can also assist students with the identification and confrontation of personal misconceptions [26] - [27].

Science classes are seen by many students to be threatening and intimidating places to be. Tobias [28] has been critical of introductory college science courses and has argued that typical classrooms are "… competitive, selective, intimidating, and designed to winnow out all but the 'top tier' … there is little attempt to create a sense of 'community' among average students of science" (p. 9). Hence, a traditional science classroom may present potential barriers that could inhibit learning for some students. The active process of writing may provide one mechanism through which these barriers to learning could be reduced and possibly even removed. Tobias [29] also indicates that writing can serve as a means to help students relieve their anxiety and help them unlearn models and techniques that have been shown to be scientifically unsound.

This article describes a novel technique for infusing writing into two distinctly different courses: an introductory physics course for non-majors and a freshman level introduction to engineering course. The techniques to be described here permit students to experience all aspects of preparing a professional paper for publication. The students' experiences culminate with a presentation of their papers at either *The New Millennium Conference* at American University (AU) or the *Sustainability in the New Millennium Conference* at the University of Pittsburgh (Pittsburgh). The specific courses in which the writing strategies were adapted, *Physics for a New Millennium* (AU) and *Introduction to Engineering Problem Solving* (Pittsburgh), will first be described. The curriculum involved in the development of the writing activity will then be discussed. This discussion will be followed by a summary of the conferences in which students participated. Feedback from student participants will also be shared. Finally, a summary of this technique will be presented in light of its relevance to science, mathematics, engineering, and technology (SMET) education.

II. The Physics for a New Millennium Course At American University

Physics for a New Millennium (PNM) is a second-tier course in the Natural Sciences portion of the General Education core at American University. All students at American University are required to take two courses within the same curricular area in the Natural Sciences. Thus, students can choose to take two courses in either biology, chemistry, physics, or psychology. Prior to enrolling in PNM, students will have first taken the foundation course *Physics for the Modern World* (PMW). Approximately 90 students enroll in PMW each semester (45 in each class session). In terms of content, the PMW course is a fairly traditional one-semester, algebra-based introductory course for non-majors. Students in PMW attend two 75-minute classes and a 2 ½ hour lab each week. Topics typically addressed in the PMW course include: Kinematics, Newton's Laws, Momentum and Energy, Rotational Motion, Fluid Mechanics, and Waves & Sound. The course includes strong conceptual and problem solving components. In addition, the course involves a writing component [30]. Although traditional in its content and format,

numerous teaching strategies have been developed for use in PMW that focus on the accommodation of students' diverse learning styles [31] - [35]. This type of course is of critical importance on college campuses often not because of the clientele, but rather because of the revenues associated with the large enrollments that are typical of such courses. In fact, this course deals with a population of students that is often overlooked, non-majors enrolled in General Education physics courses, yet they are so important as scientifically literate citizens.

The PNM course was designed to build upon the foundation laid in PMW. Because of the interactive nature of the course, the enrollment is limited to 16 students. The content of PNM includes:

- waves,
- sound,
- electricity & magnetism,
- light, optics, & color, and
- modern physics.

The PNM course was developed through the use of current research in Physics, Physics Education, and Engineering Education. As a result, the course is taught using an integrated, inquiry-based approach. Students meet once a week for a 75-minute class session and once a week for a 150-minute activity-oriented session. During these activity-oriented sessions, students are able to perform a number of interactive, hands-on, investigative activities thus enabling them to more deeply probe the topics being discussed during class.

For example, students explore the topics of Electricity & Magnetism by building electric circuits and motors. Students enjoy learning about the physics of the incandescent bulb [36], by dissecting a 3-way light bulb and switch to help them understand how each operates.

The topics of Light & Color are investigated using various hands-on optics activities and experiments. Using the quantum model of the atom, students investigate various properties of gas lamps, incandescent bulbs, and light-emitting diodes (LEDs) and are then able to link them to practical, everyday applications. This unique approach to bringing topics in Modern Physics to non-majors involved the use of award-winning interactive software and hands-on activities entitled "Visual Quantum Mechanics" (VQM) developed by the Physics Education Research Group at Kansas State University [37] - [38]. Traditionally, topics in Modern Physics are highly mathematical in nature. However, the VQM materials are very unique in that they were designed specifically with the non-major in mind, and hence, require only a minimum background in mathematics.

III. The Engineering 0012 Course

Engineering 0012 is a second-semester course in the required core for engineering students at the University of Pittsburgh. All students are required to take four core Engineering courses during their first year. There are two zero-credit seminar courses and two three-credit introductory problem solving courses that are a part of this core. ENGR0012 is a three-credit problem solving course that students typically take during the second semester of their freshman year. The course meets twice a week for 2 hours in a state-of-the-art computer classroom. ENGR0012 covers the computer programming portion of the integrated curriculum package which is now standard for

all incoming freshman engineers at the University of Pittsburgh. ENGR0012 has four main curricular goals:

1. teaching students to program a computer using a general-purpose programming language;
2. teaching students to design programs using a "top-down" approach;
3. promoting and encouraging good programming practices; and
4. illustrating the role computer programming plays in solving real-world engineering problems.

Roughly half of the ENGR0012 course is taught interactively in a cooperative learning environment. The remainder of the course is taught in a lecture environment, where emphasis is placed on the relationship between the engineering sciences and engineering design. The class sections are taught by faculty members from various departments within the School of Engineering. The course focuses on material that overlaps with various disciplines in engineering. Emphasis is placed on the application of various computer-based tools to solve real-world engineering problems. The course also illustrates how engineering differs from, as well as how it coalesces with, the disciplines of science and mathematics. During these class sessions students are introduced and coached in the following topic areas:

1) Working in Teams
2) Use of software packages (MATLAB) in problem solving,
    a. Mathematical Operations
    b. Matrix Operations
    c. Curve Fitting
    d. Plotting
    e. Input/Output
    f. Scripting
    g. Branching
    h. Looping
3) Use of software packages (C++) in problem solving,
    a. Mathematical Operations
    b. Input/Output
    c. Scripting
    d. Branching
    e. Looping
    f. Functions
    g. Pointers
4) Use of software packages (WORD, POWERPOINT) in communications.
    a. Introduction to Technical Report Writing
    b. Effective Use of the Library

Open-ended homework projects related to these topic areas are assigned. Here students have several options and must make efficient choices in order to solve the problem(s) at hand. These projects are intended to challenge students' judgment and creativity as well as their problem-solving abilities. Each student team is required to submit a final written report upon completion of each project.

The writing activity in both courses involved the preparation of a professional paper for presentation at a conference held at the end of the semester. The discussion that follows highlights this writing activity and demonstrates that regardless of class size, the experience can be a rich and robust one for students.

IV. Description of the Writing Activity Utilized at Both Institutions

This section presents a description of the writing activity developed for use in both the AU and Pittsburgh courses. The writing assignment was designed to give students experience with all aspects of preparing a formal paper for publication and presentation.

Early in the semester, students enrolled in either the AU or Pittsburgh courses were informed that one of the key components of the course would be the preparation of a formal written paper for publication and presentation at a conference to be held at the end of the term. For the PNM course students were allowed to choose a topic that interested them provided that the physics content involved closely paralleled one or more of the topics covered on the course syllabus. In addition, their chosen topic had to be congruous with the new millennium conference theme. Students were encouraged to research past, present, and future applications of their chosen topic. The key idea was to have students explore a topic(s) in more depth than would be covered in class, thus making them the "experts." Each student in the AU course wrote a single-author paper.

The theme for papers prepared for the Pittsburgh conference was a little different. Given that Pitt uses an integrated curriculum approach for their freshman courses, students were told that where possible, their papers should relate to topics covered in the fall or spring semester of their Physics, Chemistry, Calculus or Engineering classes. In addition, students were to link their chosen topics to an area of engineering using the idea of sustainability in the new millennium as the common conference thread. The key idea was to expand upon the concept of curriculum integration by having students merge material from their core courses with material they had learned in their introduction to engineering seminar courses. The hope was that the writing assignments would help the students select the best field of engineering for their interest area. In addition, because of the large class size at Pittsburgh (360 students), all papers were required to have two co-authors. After the first two years of the conference activity, it was discovered that this particular conference theme was not working for the engineering students. Instead of looking for ways that sustainability could be included in all fields of engineering, the students were taking the easy solution of writing on green construction and/or electric cars. Hence for the past 4 years the topics listed in the call for papers was changed to those related to: Bio Engineering, Civil Engineering, Chemical Engineering, Electrical Engineering, Computer Engineering, Industrial Engineering, Materials Engineering, Mechanical Engineering, design, development and/or function of a device, applications and public policy issues, and applications and social issues. There is no mention of the concept of sustainability in the call for papers. This has had a great positive impact on the diversity of topics covered by the approximately 160 papers. Students are now focusing on topics within their selected major and are using the research for the paper as a means of reinforcing their decision to major in one department or another.

Throughout the semester, students in both courses were exposed to all aspects involved in the preparation of a formal paper for publication. These aspects included: responding to a call for papers, submitting an abstract, being notified of the acceptance of their abstracts, conducting the necessary research, preparing and submitting a paper for review, conducting a review, and receiving and utilizing the feedback to prepare a final paper. Each of these items are further described and illustrated in the sub-sections presented below.

The Call for Papers

The conference call for papers was distributed at the beginning of the semester. Students received a paper copy as well as an electronic copy of the call via the class listserv and web page.

The purpose of having students prepare an abstract was threefold. First, the preparation of an abstract gave students a sense for how the abstract submission process is handled for a professional conference. Second, it provided students the incentive to choose a topic for their papers early and to begin to focus on the research aspects of the project. Third, based on the first few years of conference experiences, it was obvious that many students had never been asked to prepare an abstract before. Many students were challenged to effectively summarize a paper they have not yet written into a 150 – 200 word abstract. Thus, this task required the students to think within the "big picture".

The call for papers marked the beginning of a semester-long research and writing project for the students. Students were informed that the only difference between submitting an abstract for their respective conferences and an actual conference was that their abstracts WOULD definitely be accepted!

To assist the students in the development of their abstract, the English faculty at Pittsburgh developed research guidelines to help the student write their abstracts. These guidelines were also used at AU. It was also discovered that the students lacked the necessary library skills needed to properly research their topic to write an effective abstract. Thus, the library staff at Pitt developed a digital tour of the library and posted guides to help the students with their research. Students at AU learned to work closely with library faculty and staff.

Notification of Acceptance of Abstracts

A web-based electronic format was used for submission of abstracts. The electronic submission of abstracts encouraged professionalism from the outset of the paper preparation process and facilitated a more efficient and effective review.

Once the submission process was completed, all abstracts were reviewed by the course instructors. Approximately one week after the submission of their abstracts, students were informed (electronically) that their abstracts had been accepted. The abstract review also allowed the instructors to prepare a preliminary conference schedule and to make sure the paper topics were consistent with the call for papers. Some students were asked to revise their abstracts because their initial topics did not parallel the conference theme closely enough.

After the first conference experience at Pittsburgh it was discovered that the engineering faculty for ENGR0012 could not handle the volume of abstracts generated by the conference. Thus, starting in the second year, faculty from the English department were used to review the abstracts. The administrative technique used to make the English faculty available, was to making the writing components in the first year ENGR0011 and ENGR0012 meet the freshman English writing requirement. Students at Pittsburgh take ENGR0011 prior to taking ENGR0012. Thus, the freshmen engineering students do not take an introductory college writing class. This frees the English faculty to work with the Engineering faculty throughout the year.

Conducting the Necessary Research

Upon receipt of the formal acceptance of their abstracts, students at AU are instructed to set up an appointment to discuss the comments and suggestions provided by their instructor. Students are asked to bring all of the research materials that they had collected thus far with them to their appointment. Viewing the research materials allowed the instructor to help students narrow and refine their topics. In addition, the students at AU are non-majors with a modest mathematical background. Hence, the meeting allows the instructor to ascertain whether or not the chosen topic is at a mathematical level appropriate for study for the students. After this meeting, students began the process of collecting additional resources as well as preparing a first draft of their written papers for formal review.

The process at Pittsburgh was a little different. Students there began writing smaller research papers during their first semester Problem Solving Course (ENGR0011). A typical paper involved researching and reporting on a particular field of engineering that was of interest to the students. The paper was integrated with the Freshman Seminar course (ENGR0081), which utilized undergraduate engineering student mentors and advisors in the Engineering program to assist students with the writing process. As part of this assignment, students were instructed on the use of the library, how to format a research paper, and how to give an oral presentation. Thus, ENGR0011 was used as the preparation for the conference assignment that was part of the second semester course ENGR0012. An important lesson that was learned with the writing assignment is that students need continuous feedback throughout the entire process.

ENGR0012 is integrated with the second semester Freshman Seminar course (ENGR0082), and student mentors again provided assistance to the students during the writing of their papers. To facilitate this process, each of the 180 teams of student authors met weekly to give a short progress report. During these meetings students must demonstrate completion of various milestones set by the English faculty. For example, during one weekly meeting students were required to submit an extended 2-page outline of their papers, during another they were required to submit a copy of the articles they were using for their papers, and during another they were required to submit short summaries of each of the articles they had collected thus far. As was the case with the abstracts, the English faculty design research guides for the students to follow when writing their outlines and annotated bibliographies.

Preparing and Submitting a Formal Paper for Review

When students initially receive notification that their abstracts have been accepted, they are given a copy of the paper formatting guidelines to be followed as they prepared their papers. The guidelines that were given to the students were essentially the same guidelines given to authors submitting a paper to the Frontiers in Education Conference. Sample papers utilizing these guidelines that had been written by the authors and previous students (with permission) were also made available to the students.

Receiving Reviewers' Feedback

All students' papers were subjected to a formal review process. At AU the instructor conducts the reviews of the first paper drafts. Once the reviews are completed, each student meets individually with the instructor to discuss the feedback and comments they have received. At this point in the semester, some students typically turn in papers that need very little additional work, while others turned in papers that still needed a substantial amount of revision. All students are then required to prepare a second draft of their papers. The second draft undergoes a formal peer review. Each student is required to carefully and thoughtfully review one of their "student colleague's" papers.

Because there are approximately 16 papers in the AU conference the instructor can act both as a reviewer and as the conference session chair. At Pittsburgh this method is not an option with approximately 160 papers to be presented. Thus, the Pittsburgh conference makes use of 3 time slots with approximately 10 concurrent sessions during each slot. This results in approximately 30 sessions with 6 papers presented per session. Because of the large number of papers to be presented it is not possible for one person to perform all the associated tasks. To address this issue, approximately 30 alumni volunteers from the Pittsburgh area together with approximately 30 peer mentors are solicited to act as co-chairs for each session. During the first two conference years, each session was co-chaired by one alumni and one upper class engineering student. These individuals also served as reviewers for the papers to be presented in their sessions. In the beginning student co-chairs were not used. However, it was found that the alumni volunteers could not always meet the entire semester long commitment. Thus, there would be sessions in which students did not always get the necessary feedback they needed throughout the semester. Thus, for the last 4 years upper class engineering students have been added as peer mentors to act as co-chairs, to assist the alumni.

The paper review is a two step process. After the abstracts are submitted, the ENGR0012 faculty initially reviewed the abstracts to establish the 30 sessions. Students are then required to submit an extended outline and annotated bibliography of their papers. This material is emailed to the session co-chairs and English faculty, who then meet with their students to discuss the paper outlines. After this meeting students prepare the draft version of their papers and submit it electronically. The co-chairs are responsible for reviewing these submissions for technical content. A second meeting with the students to discuss the reviewers' comments is then held. In addition to being reviewed by the co-chairs, each paper is also reviewed by a faculty member in the English department. The reviews conducted by the English faculty members focused on writing style, form, and grammar.

A peer review process was implemented at both institutions. The usefulness of this approach has been widely documented [39] - [40]. Thus, in both courses, every student is assigned another student's paper to review. At the Pittsburgh each paper has two authors which means that each paper is peer reviewed by two students. This review process is web-based so students are able to submit their review comments online. The comments are then automatically sent to the respective authors via email.

In sum, at AU this process produced 3 independent reviews, one from the students and two from the instructor. At Pittsburgh this process produced 5 independent reviews, one from a faculty member in the English department, one from an alumni, one from a peer mentor and two from students.

Revision of Papers for Conference Proceedings

Students utilize the reviewers' comments to prepare final copies of their papers. At Pittsburgh, the revision process was also used to introduce the concept of sustainability. During the revision phase, a new requirement is added to the paper that requires every paper to include a one page discussion of the impact the paper topic has on sustainability. This "change order" now accomplishes the task of having every student consider sustainability as it relates to their field and not just to green construction.

Typical papers at both institutions range in length from 5 – 8 formatted pages. At AU the submitted papers are then arranged according to "common themes." A spiral-bound conference proceeding is produced and distributed to each student on the day of the conference. Many AU students have used this paper as a formal writing sample when applying for internships and their first jobs. At Pittsburgh, because of the magnitude of the conference, a conference matrix was created and distributed at the conference rather than a formal set of proceedings.

V. The Conference

The conference held at AU is traditionally held on the last day of class. The class period is of an extended length which is directly related to the actual enrollment in the course. Students are not required to take a final exam. The conference paper and presentation take its place and are given a significant weighting in the determination of students' course grades (approximately 35%). In addition, students are given one class period free during the semester (strategically timed prior to submission of their second drafts) to give them time to work on their papers and to compensate them for the longer class period on the day of the conference.

Two days prior to the actual conference, students at AU meet with the instructor to go through a practice-run of their presentations. The students prepare and make use of overhead transparencies, PowerPoint slides, and demonstrations during their presentations. Students are also asked to wear appropriate attire for the conference. At Pittsburgh, students meet with their peer mentors to practice their presentations prior to the conference. For both conferences a light lunch is also provided.

Students are given 10 minutes for their presentations and then allowed two minutes for questions. Overall, the presentations made by students are very professionally done.

At Pittsburgh, it is not possible to hold the conference during regular class time because of the sheer size of the conference. Thus, the conference is held from 8 am to 4 pm on a Saturday near the end of the spring semester. The Pittsburgh conference also awards best papers for each session, and best overall conference papers. The best papers are given a cash award.

The conferences attract a good amount of attention at both American University and the University of Pittsburgh. During the AU conference, students often enjoy visits from the Dean and other faculty members. In addition to the faculty presence at the conference, friends and family members are also invited to the conference. At AU, letters are actually sent to the parents along with a copy of the conference program. Having the students' friends and parents present has greatly improved the quality of the presentations at both institutions. The following section highlights student impressions regarding their overall experiences during the paper preparation process.

VI. Feedback From Students

Near the beginning of each semester, the students were quite apprehensive about the prospect of preparing a formal written paper. Most students had never been given a writing assignment of this magnitude before. Although the students have done some writing when they were enrolled in the foundation course, PMW, and in ENGR0011, the task facing them seemed quite daunting. In addition, many students expressed anxiety regarding the fact that they were also being asked to present their papers orally. Comments from students suggested that they felt they would never be able to fill the 10-minute time period allotted them for their presentations. In reality, once students had completed their written papers and had prepared their materials for presentation, most found that they had too much material to fill the 10-minute time slot! Thus, the real challenge faced by most students was the condensation of their papers into a 10-minute presentation. Each and every student author was, however, successfully able to present their papers within the given time period.

On a questionnaire given students near the end of previous semesters, students were asked to describe their overall impressions regarding the conference paper assignment. Typical student responses included:

- *I've never written a technical paper like that before. The topic was much more involved and required you to really understand what you were writing about.*
- *I thought this was a difficult assignment that taught me a lot and was worth doing. It was a lot of work, but after doing it, I felt like I learned a lot. I never had to write a technical paper before and I'm happy that I can now say that I wrote a conference paper.*
- *I learned a lot about a subject that I would not otherwise have learned about. I had never written one of this magnitude, or that required so much in-depth research. We were allowed to pick the topic - which was nice.*
- *I have never written any form of technical paper at all. At first, I was not very excited about the idea of writing such a paper, but I did feel that I had a very valuable experience. I feel that I have learned so much - beyond physics principles. I also appreciated you forcing us to do rough drafts, so I was able to pace myself and put more effort into it than I otherwise would have.*

At the conclusion of the conferences, it was clear that the students felt that all of the time, energy, and hard work they had devoted to the preparation for the conference had paid off. Many expressed that they had experienced a fairly steep learning curve on both the content covered as well as the rules and regulations they were required to follow as they prepared their formal papers. In addition, many students expressed gratitude for the opportunity they were provided to participate in such a formal and professional activity.

VII. Summary and Conclusions

All aspects of the conferences, from submission of an abstract to the formal submission of a camera-ready copy of their paper for publication and presentation, allowed students the opportunity to link the active process of writing to sound, scientific content. In addition, these activities allowed students to demonstrate their understanding of a topic or set of topics using their individual learning styles. This activity also provided the instructors with an additional assessment tool outside of the limits of more traditional assessment measures.

The underlying premise is that all students, no matter what their gender, cultural, or demographic backgrounds, can learn! In a recent report on its review of undergraduate education, the Advisory Committee to the National Science Foundation's Directorate for Education and Human Resources concluded that "… while K – 12 programming can expand the pool of those interested in pursing careers in SME&T [Science, Mathematics, Engineering, & Technology], it is at the undergraduate level where attrition and burnout can be most effectively prevented. What we in SME&T education must do is to concern ourselves with *all* students, not just those who historically have been represented in science, mathematics, engineering, and technology. Such a breadth of concern has important educational benefits as well, as it will force us to think more about how individuals learn and recognize what research has made clear: that there are differences in learning style which profoundly effect achievement. And let us not forget that increasing student achievement in SME&T education is exactly what is needed [41]" (p. 28).

Writing has proven to be an effective way to assist students in articulating their thoughts. In addition, the opportunity to research and then write about a topic of personal interest can allow students a chance to demonstrate their understanding in a way traditional assessment measures do not permit. Hence, the application of a writing component into a course for majors as well as non-majors has enormous potential within both science and engineering communities.

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