Writing and Physics: A Powerful Linkage in General Education

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Abstract — During the Fall 2000 and Fall 2001 semesters, a joint study was undertaken between the Physics and Literature Departments at American University. The study involved the linking of two introductory general education Liberal Arts courses: an introductory physics class for non-majors and an introductory college writing class. One goal of the study was to provide more content-specific writing assignments within the college writing class by linking them to material being covered in the physics class. The writing assignments given in both classes formed the basis of the data collected during the study. The underlying questions behind the study involved the assessment of student learning in physics as well as in college writing. The primary research questions were: (1) Could this course linkage serve to enhance the motivation of Liberal Arts students to think more deeply and critically about the physics-specific content they were writing about in each class? (2) If so, could this enhanced motivation be linked to increased student understanding? In this paper, highlights of the curricula developed for the linked classes will be provided along with results of the assessment of student learning. This study should have broad-based applications for other educators within the domains of SMET education, particularly those interested in courses designed for Liberal Arts majors

I. Introduction

The primary purpose of teaching is to facilitate student learning. However, many traditional teaching methods have clearly been shown to encourage passive rather than active learning [1], and passive learning hinders comprehension and long-term retention of important concepts. Students in traditional classrooms acquire most of their knowledge through classroom lectures and textbook reading, but good teaching involves a great deal more than simply pouring information into their heads. Students do not enter the classroom with a tabula rasa. They bring their own world views which have been developed and formed over their lifetimes [2]. Students' world views often differ greatly from that of scientists and engineers. Often, due in large part to these differences, students emerge from our classes with serious misconceptions [3] -[7].

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 [8] -[15]. The use of writing in introductory physics classes for non-majors may help students develop their critical thinking and problem-solving skills. In addition, writing can help them identify and confront their misconceptions about a specific topic in physics.

Science classes in particular are seen by many students as threatening and intimidating. Tobias [16] has been critical of introductory college science courses, arguing 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 barriers that inhibit learning for some students. The active process of writing provides a non-threatening mechanism through which students could reduce or even remove these barriers to learning. Tobias [17] also indicates that writing can serve as a means to help students relieve their anxiety, and help them unlearn models and techniques that have proven scientifically unsound.

This paper describes a novel technique for infusing more writing into the introductory physics curriculum for non-majors by linking one section with an introductory college writing class. The course linkage was designed to provide more physics- and science-related writing assignments within the college writing class by linking them to material being covered in the physics class. In addition, some of the college writing class assignments directly followed writing assignments given in the physics class, thus enhancing the course linkage.

The sections that follow describe each of the courses involved in this study, along with the curriculum developed to link the two courses. In addition, information regarding assessment techniques will be provided. Finally, the authors will share some general observations and preliminary conclusions based on their experiences. These observations and experiences should provide useful information for other educators interested in weaving more writing into the introductory curriculum either for majors or non-majors.

II. Description of the "Linked" Courses

As part of the General Education requirements towards graduation at American University, students are required to take a 2-semester sequence of courses in Curricular Area 5, the Natural Sciences. Students first choose to take a foundation course in Biology, Chemistry, Psychology, or Physics. Students who select Physics will enroll in *Physics for the Modern World*. Upon completion of the foundation course, students choose from six second-tier courses designed to complement and build upon the topics learned in *Physics for the Modern World.*

The General Education requirements at American University also require a College Writing component designed to help develop students' skills in reading, in gathering and synthesizing information, and in writing correct, reasoned prose. The particular writing course linked with *Physics for the Modern World* during the Fall 2000 and Fall 2001 semesters was entitled *College Writing: Composing the Physical World.* The subsections that follow briefly describe each of these courses.

A. Physics for the Modern World

The introductory foundation course in Physics for non-science majors at American University in Washington, D.C. is a one-semester, algebra-based course entitled *Physics for the Modern World* (PMW). Topics covered in the PMW course typically include Kinematics, Newton's Laws, Conservation of Momentum and Energy, Rotational Motion, Fluid Mechanics, Waves, and Sound. Although traditional in its content, the course is not taught in a traditional lecture format. Numerous teaching strategies have been developed which correspond to the accommodation of students' needs and diverse learning styles [18] - [23]. One such strategy involves the use of writing [24] - [25]. A significant amount of research conducted in the sciences and in engineering

suggests that the active process of writing can be an effective teaching and learning tool. In addition, the PMW course includes strong conceptual and problem solving components.

B. College Writing: Composing the Physical World

The college writing class asked students to look beyond equations to investigate the relationship physics has to literature, philosophy, history, and Western culture. Students were asked to think about what physics could teach them about the world, about themselves, and about society as a whole. Although some assignments were given with the goal of satisfying the general goals of a typical college writing class, others were specifically linked to physics or to science, in general.

During each fall semester, 2 lecture sections (typically totaling an average of 120 students) of *Physics for the Modern World* were offered. The 2 lecture sections were broken into 8 laboratory sections, with an average of 16 students in each lab. One of the 8 laboratory sections (a section consisting of 7 students) was linked with one section of college writing (*Composing the Physical World).* Although *Physics for the Modern World* typically consists of freshman through seniors, all students enrolled in the linked courses were freshman - the College Writing class is a mandatory requirement for all American University students, and the logical plan is for students to complete College Writing during their freshman year. A description of the curricular tools developed to link *Physics for the Modern World* and *Composing the Physical World* follows.

III. Curricular Tools Designed to Link Physics with College Writing

As part of their homework assignments in the physics class, students are given short writing activities in the form of "folder assignments" (submitted to the instructor in a two-pocket folder; hence the name). Typically, students receive 5 folder assignments each semester. Upon collection of the folders, a block of time is set aside (approximately 6 - 8 hours) by the instructor to read them and provide each student with written feedback. This written feedback is absolutely essential. Numerous studies have pointed out the importance and value of prompt and thoughtful feedback to students [26] - [30]. When students take time to reflect on their writing and on the comments provided, it helps them uncover and wrestle with their misconceptions about the Physics concepts. All the while learning is taking place.

The content and structure of the writing assignments vary, depending on the goals and objectives for a particular topic or content area. For example, some assignments asked students to explain a problem or a concept that was discussed during a class session. Thus, students essentially have the answer to the problem in their hands when they write up the assignment. The rationale for this is that learning can be enhanced when students take on the role of teacher through their detailed responses and explanations. For other assignments students are sometimes asked to think and write about a question that pertains to content yet to be discussed during class. This helps students tune-in when the question resurfaces during a later class session. Typical folder activities range in length from 1 - 4 pages.

Through the folder activities, students are encouraged to share their understanding of a particular topic or concept in their own words - with no pressure to use scientific jargon. This

gives a much clearer window into the students' thoughts and to their current levels of understanding.

During both semesters of the link, 5 folder assignments were given to all students taking the physics course. Three of these assignments were specifically designed to link to assignments in the college writing class. The assignments given in the college writing class were called "concept papers." The concept papers were designed to allow students to elevate their understanding of concepts presented in the physics class. The concept paper assignments were always given after a folder assignment had been completed. Furthermore, for each concept paper students were asked to have a specific audience in mind when they wrote (a different audience for each paper). Thus the folder assignments served as a baseline for the concept papers. A description of each of the linked assignments follows.

A. Fall 2000

Linked Assignment #1

Near the beginning of the semester students in the physics class were studying motion concepts and the application of the constant acceleration equations to numerical (as well as conceptual) problem solving. During one class session, a one-dimensional motion problem was worked out in its entirety. Students were then given a folder assignment asking them to prepare an explanation of this problem for a classmate who happened to miss class that day. Students were asked to prepare a narrative that would clearly outline for their classmate the key ideas involved with the solution to the problem worked out in class. Thus, students had the "answer" to the problem in their hands when they wrote up their folder assignments.

The first concept paper assignment followed shortly and asked the students to write a 2-page paper (the required length of all concept papers) that explained the concepts of motion, specifically acceleration to an audience of the students' choice. Students were required to clearly articulate who their specific intended audience was. Students were also encouraged to make use of analogies, anecdotes and/or metaphors to illustrate their explanations.

Linked Assignment #2

The second linked assignment involved the physics concepts of momentum and impulse. In their folder assignments students were given a specific scenario from which they were to demonstrate their understanding of these concepts. The scenario involved a minor traffic accident between a Mazda Miata and a Ford Explorer. The students were asked to imagine that they were a passenger in the Miata that was being driven by a friend. Then, while stopped at a traffic light, the Miata was hit from behind by the Ford Explorer. Students were then asked to answer the following questions: *1) Upon which vehicle was the force of the collision the greatest? 2) Which vehicle will have the greater acceleration during the collision? 3) Which vehicle will experience the greater change in momentum? 4) Which vehicle will experience the greater impulse?* Students were given the freedom to be creative with this assignment. Many were very creative, completing the scenario with a variety of endings.

The concept paper that followed this assignment asked students to write a paper that explained, from the point of view of the Miata passenger, to the Miata driver why his/her car took the brunt of the damage in the collision with the Ford Explorer. Students were instructed to use scientific concepts to back up their explanations, but were cautioned not to speak over the heads of their audience. They were also reminded that the Miata driver was not a scientist. Again students were encouraged to use analogies, anecdotes, and evidence from the collision in their explanations.

Linked Assignment #3

The third linked assignment was given near the end of the semester when students were learning about fluid mechanics in the physics class. The folder assignment centered on students' understanding of Archimedes' Principle and buoyancy. In particular, students were told they were having a discussion over lunch with a friend when the following question came up: *A bucket partially filled with water rests on a scale. Does the scale reading change when a lead block is suspended from a thread and lowered into the water where it is held submerged without touching the bottom or sides of the bucket? (No water spills out of the bucket when the lead is lowered into it.* The students were then told that their friend answered this question by saying that the scale reading doesn't change (incorrect response). Students were told they must disagree with their friend and use the physics concepts being discussed in class to explain the correct response to the question.

Students were also asked to explain a second related question that came up during their lunchtime discussion with the friend: If the lead block in the previous question was suspended from a spring scale, what happens to the reading of that scale when the block is submerged in water. The students were told that their friend said that the scale reading would increase (incorrect response). Students were again told that they must disagree with their friend and use the physics concepts being discussed in class to explain the correct response to the question. Finally, students were asked to rate their level of confidence in their responses using a scale from 1 - 10 (with 10 being the highest).

The concept paper that followed required students to play the role of a physics teacher and instruct the class about Archimedes' Principle, using the lead bucket example described above. Students were asked to keep in mind that their audience was made up of their physics classmates and that all were non-science majors.

B. Fall 2001

For the linked assignments in the Fall 2001 term, the instructors wanted to encourage the students to be a bit more creative and elaborate in presenting their understanding of the physical concepts. Thus the Folder and Concept Paper Assignments worked hard to set up vivid scenarios that, hopefully, sparked the students' imaginations, and helped them to see the practical applications of physical concepts in their everyday lives. The Fall 2001 Folder and Concept Paper Assignments borrowed their forms from their Fall 2000 predecessors, with the following improvements.

Linked Assignment #1

The Folder Assignment in this case took as a model the Fall 2000 Mazda Miata folder assignment (see Linked Assignment #2 above), asking students to assume they'd been involved in a car accident with Mitsubishi Spiders and two other vehicles. Again, the students were to explain the collisions in terms of momentum and energy. The Concept Paper asked the students to build a narrative around the accident, inventing characters and point of view. Most importantly, students had to present an explanation of the physical concepts of the collision in plain language. The protagonist of this narrative, the students were told, has a working knowledge of the physical concepts, and the audience (the protagonist's friend) knows very little about physics.

Linked Assignment #2

The Folder Assignment set up this scenario: "A 4.3 N ceramic flowerpot falls off the fence around your back deck and lands on the grass-covered ground below. The fence is 1.37 m above the ground. In coming to a complete stop, the flowerpot penetrates into the ground a distance of 2.6 cm." The students are then asked to put on their "teacher-hats" and explain this problem to a friend (who's currently taking the physics class): how can one determine the average force that the ground exerts on the flowerpot as it comes to a stop. In their explanations, the students are asked to use energy techniques to guide the friend to the solution.

The Concept Paper assignment asked the students to write a narrative about a physics teacher leading a class on a field trip to a D.C. destination where he or she can apply the flowerpot scenario to another object (it doesn't matter the destination or the object), and explain to the class how they could determine (in terms of momentum and energy) the force of the ground on that object were it to fall. The teacher may, for the sake of the comparison, estimate the weight of the object and its distance from the ground before it falls. Again, the assignment asks the students to use narrative techniques: write in the first or third person, write in scene— build a world around the characters and put the audience in a place (or places) and a time of day. The audience for this narrative would be made up of people with no particular background in physics, so again, plain language is important.

Linked Assignment #3

The Folder Assignment asked students to respond to two questions, using their knowledge of fluid mechanics: "1) You and a friend are at the beach on a beautiful, sunny day. You slowly walk out into the water (it's kind of cold at first, you know how that goes). As you do you find there are stones underneath your feet that cause a little bit of pain at first. You find, however, that as you walk further into the water, the stones under your feet don't hurt as much. Why do you think that is? 2) After a nice swim you and your friend have an opportunity to take a little sailboat ride. As you get onto the sailboat you immediately put life preservers on your back. What is the function of the life preservers?"

The Concept Paper Assignment asked students to write a letter as if to send it home to a parent or guardian. The letter would describe an incident involving the student and a friend swimming at Ocean City in Maryland. Before swimming, the two friends put on life-preservers,

one full of Styrofoam, the other full of lead pellets. The letter will describe what happened when the two friends dove in the water— which one would float, which one would sink and why. The students were also to use the letter as a way to assure their parent or guardian that they were learning a lot during their first semester of college.

Additional Linked Assignments

In addition to the linkage between the folder activities and the concept papers, students in the college writing class were given some additional reading and writing assignments that were in some way related to science. In Fall 2000, the College Writing texts included a book by Michael Guillen entitled *Five Equations that Changed the World* [31] and a play by David Frayn entitled *Copenhagen* [32]. The book highlights the life's work of 5 well known scientists while the play offers an interpretation of the mysterious and controversial meetings between Niels Bohr and Werner Heisenberg in 1941. In the Fall 2001 class, Copenhagen again was used, but the Guillen book was not. In place of Guillen, the students read *Einstein's Dreams* [33], a book by Alan Lightman that explores alternate versions of the properties of time as Albert Einstein might have envisioned them, and *Cosmicomics* [34] by Italo Calvino, a book of shorts stories wherein each character is actually a scientific equation. Both *Einstein's Dreams* and *Cosmicomics* served to encourage students to question their notions about physics, and it, more than the Guillen text, provided a way to think creatively about science and still remain focused on the kinds of things they were learning in the Physics class.

Four additional writing assignments were given students in the college writing class. In the **Fall 2000** section, these assignments included an *Editorial,* an *Interview,* an *Advertising Analysis,* and a *Creative Assignment*. Each of these assignments is briefly outlined below.

Editorial Assignment

For the Editorial assignment, students were asked to compile appropriate resources (articles, books, web sites, etc.) that would assist them in taking a stand on one of two current controversial issues: 1) requiring science classes for non-majors, or 2) the effectiveness of single-sex math and science education. In their editorials students were to explore the nuances of their chosen issue and recommend a course of action. Students were required to write a 4 - 5 page paper that made use of at least 4 resources to support their analyses and opinions.

Interview Assignment

The Interview assignment provided students an opportunity to profile a practicing scientist and his or her work. Many students contacted their physics professor for assistance in selecting a scientist for their interviews. The students' written profiles were required to be approximately 5 - 7 pages in length.

Advertising Assignment

Within the Advertising assignments students were asked to analyze product ads to expose their misuse of science to manipulate the consumer. Students could choose any products they wanted to (from cereal to cellular phones, mouthwash to mayonnaise, beauty cream to batteries). The task of the students was to delineate the advertisements' implicit and explicit "scientific" claims, exploring the tactics they use to convince their audiences to buy. Students were required to have a minimum of 2 sources to support their analyses. In addition, students were required to attach the ads they analyzed to their final written paper, which was approximately 4 - 6 pages in length.

Creative Assignment

The Creative assignment provided students some flexibility. Students were given 3 options to satisfy this assignment. The first option involved the writing of a 3 - 4 page children's story that would explain a physical concept to young children between the ages of 5 and 9. Students were allowed to choose which physical concept they wanted to explain and they could also decide in what context they wanted to present it. Students were also required to make use of illustrations when writing their stories; however, the type of illustration to be used was at the discretion of the students.

The second option for the assignment was linked to the model represented in Guillen's book. Students were asked to use the chapters in this book as a model to write a profile of either Niels Bohr or Werner Heisenberg. In his book, Guillen builds each chapter around the life story of the scientist, culminating either in one important scientific discovery, or in a series of discoveries. For this assignments students were to make use of at least 3 outside resources to prepare a 4 - 6 page paper appropriate for an audience of non-scientists.

The third option for the Creative assignment was to write a short story (5 - 9 pages in length) or a poem cycle (at least 4 poems) with science as an element. Students were given the flexibility to decide how to include that element. Students were instructed that the story/poems must be polished and should confront complex ideas or emotions (in other words, no unearned happy endings).

The section that follows gives a brief summary of the techniques used to assess students' work. Note that work done in the physics class did not affect the grade a student received in the college writing class and vice versa.

In the **Fall 2001** section, the additional assignments included a Resource Compilation, a Research Paper, a Personal Essay, and an Analytical Essay.

Resource Compilation

This assignment, students were told, would accomplish two things: 1) it would introduce them to the campus library, and 2) it would help them get a head-start on their Research Paper (see below). Students were asked to choose a topic (one that they may decide to use for their

Research Paper or not), and find sources (books, magazine and newspaper articles, journal articles, web sites) that would help them write a paper about the topic. The sources must be listed using proper MLA (standard for all College Writing classes) style.

Research Paper

This assignment asked students to choose a concept or issue that they'd encountered in their physics class. They would conduct research on the topic, assess the sources they found in an Annotated Bibliography, organize the information they gathered, and present it to a general audience in a clear, engaging paper. This Research Paper (like the Editorial of the previous year) is the cornerstone of College Writing classes, and dominated the semester. In future links, incidently, the instructors have decided that this assignment would be more beneficial if the students were given a list of appropriate topics, all generated by the instructors using the material from the physics class. Without that kind of structure, a number of the students had trouble choosing a viable topic, and thus lost a good deal of time.

Personal Essay

This assignment grew out of the September 11th, 2001 tragedies, and was not on the original syllabus of the College Writing class. This assignment has no real link to the physics class — it asked students to venture off campus to a destination of their choosing, and describe their reactions to what they saw and experienced. It was meant to help students deal with the trauma of the tragedy, and it was a substitution for a planned Interview paper.

Analytical Essay

This assignment asked students to respond to and analyze one of the course texts — they could think of it as a thesis paper, arguing their interpretation of an element of one or more of the texts. The students would construct their papers around a clear statement of thesis. The audience for the paper, they were told, had already read the texts, and should be able to 1) understand it and agree with it, and 2) argue against it. The purpose of this assignment was to help students develop as thinkers and readers, and to help them develop their skills in argument and persuasion.

IV. Assessment of Student Learning

In terms of assessment, each instructor was responsible for framing each activity's goals and objectives and for determining the assessment plan for each. In this section the assessment of the two primary linked activities (the folder activties and the concept papers) is outlined.

A. Assessment of Folder Activities

In terms of assessing the quality of the folder activities in the physics class, students were provided with a checklist of expectations on the course syllabus. The key element of the checklist involved the thoroughness with which they presented their responses. For example, a simple opinion statement that is unsupported by a physics principle or relationship would be considered a weak entry. A strong entry would be complete, well documented, and illustrating the physics

involved. The folder activities constitute approximately 10% of a student's overall grade in the physics course. Other assessment measures included homework assignments, quizzes, exams, and written laboratory reports.

The assessment strategy for the folders is unique. Students were not penalized for incorrect use of physics. This helps to make the folder assignments non-threatening. In fact, no numerical grade is put on their folder assignments at all until the end of the semester. The students have indicated that they aren't bothered by the lack of a grade; in fact, they value the feedback they receive and genuinely look forward to reading the comments on their papers. Thus, students are encouraged to look at and digest the written feedback, rather than a numerical score when their folders are returned to them. Students are encouraged to think deeply about the feedback they've received and then do whatever they need to do to correct existing flaws in their thinking. This assessment technique attempts to get students away from just looking at their numerical scores and then filing the activity away where it may never be looked at again.

In addition, the folder assignments are not graded for grammar and spelling. If a word is misspelled or some other grammatical error is found, it will be pointed out to the student, but they will not be marked down for it. However, the papers that students turn in are remarkably well written and grammatically "clean." Students have commented that because their papers are read so thoroughly and because they receive quality feedback, this provides additional incentive for them to do a good job. Consequently the feedback provided to the students has an added benefit, as it seems to encourage them to put even more thought and energy into what they turn in.

The folder activities also provide an additional assessment tool beyond such things as traditional paper and pencil tests. However, there is one shortcoming to the folder activities, and that is that they do take time to read and respond to, especially for instructors dealing with large numbers of students. One strategy that works well for handling and working with such large numbers is to sometimes stagger the assignments. For example, it can be particularly enlightening to ask students in one section to respond to a question on a particular topic *before* it has been discussed in class and the other section to respond to the same question *after* it has been discussed in class.

B. Assessment of Concept Papers

In the college writing class students were provided with some basic formatting for their papers. Students were reminded that they should take pride in their work and that their papers should be clean (including proper headings, etc.). Students were also told that their papers should be mechanically perfect and were encouraged to use spell-checkers and grammar checkers (but to use them wisely). Additional formatting guidelines for the writing assignments were presented during class. In the Fall 2000 class, the concept papers constituted 10% of the students' grade in the college writing class. The Editorial, Interview, and Advertising assignments were worth 15% each, and the Creative assignment was worth 10%. In the Fall 2001 class, each concept paper was worth 5% of the final grade. The Resource Compilation was also worth 5%. The Research Paper was worth 25%, and the Analytical and Personal Essays were worth 15% each.
In addition to these requirements, students were required to make a substantial revision of one of their writing assignments. The revision would be graded both on how good it is on its own, as

well as on how much it differs from the previous draft. Changes in style or voice, drastic reorganization, and risky, new thinking were strongly encouraged and rewarded. Students were told that revisions that were submitted that had only copy editing (i.e. grammatical, sentence-level) changes would receive an automatic "F." Students were allowed to turn in their revisions at any point during the semester. In addition, students were encouraged (but not required) to revise more than one paper during the semester. Students choosing to submit revisions that met the above standards were able to improve their scores on that particular writing assignment.

V. Observations and Preliminary Conclusions

Between the first and second years of the link, the instructors instituted a few improvements. The Folder Assignment/Concept Paper links were strengthened through more elaborate assignment instructions that encouraged students to write creatively about the concepts they were learning. In addition, the Research Papers in the College Writing class led to informal Research Presentations in front of an audience of the College Writing class and both instructors. Next year, the instructors hope to expand on that idea. For example, we envision an assignment that could be an extension of the existing Concept Paper assignment: a student-led presentation project, with the presentation being more formal. Each student would either lead the class in a discussion of a physical concept, or demonstrate the concept to the class. To aid in these presentations, audio-visual and/or computer presentation equipment could be made available. The goal of such an assignment would be to extend the stated goals of the folder assignments and concept papers: to challenge students to think about these physical concepts in different ways, and to increase the opportunities for retaining the information learned in both classes. In addition, students would benefit simply from the challenges of preparing and delivering an oral and visual presentation - a discussion about how each student prepared for their presentation could be steered into a discussion about the organization of ideas, research, and ultimately about written expression.

The instructors also plan to occasionally gather the students together for events (on-campus or off) that have relevance to our courses. Such events might include speeches, plays, films, and exhibits. Other possibilities for outside-of-class activities include study sessions and informal discussions of relevant news or cultural events. The instructors also hope to be a more visible presence in each other's classes - this reinforces the sense of community.

We also want to strengthen the assessment element of the link. We plan to create a semester-long program of assessment whereby we can gauge the effectiveness of the link in the learning progress of each student. Such a program would enable us to build upon our research in this area.

In conclusion, writing has proven to be an effective way to assist students in articulating their thoughts and their understanding about a topic or set of topics. The opportunity to 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 non-majors as well as majors, has enormous potential within the science and engineering communities.

Acknowledgments

Partial support for this work was made possible through funding from the General Education Program at American University. Any opinions expressed in this article are the authors' and do not necessarily represent the opinions of the General Education Program.

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