Linking facts with judgment: a critical thinking component in introductory calculus physics for engineering students

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Linking facts with judgment: a critical thinking activity in introductory calculus physics for engineering students

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Abstract

On the popular website, Wikipedia, critical thinking has been summarized as "an objective analysis of facts to form a judgment". The problem solving skills that require algebra and calculus are often perceived by students as pieces of information to be memorized, while the judgment forming skills needed by engineering students necessitate the linking of known facts with new pieces of information. One example in the field of electricity and magnetism, the vector cross product embedded in the Biot-Savart law, could be solved using basic trigonometry when the underlying symmetry is given, or with the 3-dimensional vector notation system. The decision made by the student as to whether the vector notation system should be applied becomes important in the asymmetrical case, such as that of a straight current-carrying wire and a current loop. By emphasizing the importance of decision making in this example, students can develop a better conceptual understanding of magnetic reconnection at the introductory calculus physics level.

Keywords

Critical thinking, memorization, facts, judgment, asymmetry, Biot-Savart law

Introduction

A July 2016 Barnes & Noble College and Money.com article reported that "Today's college students are more interested in gaining exposure to new ideas and developing critical thinking skills that lead to a fulfilling career versus chasing financial success"[1]. The magazine also published more detailed data on what students and parents consider the top three benefits of a college education. The survey showed that 84% of students and 95% of parents regarded the development of critical thinking to be a top college goal while 90% of students and 93% of parents regarded preparation for a fulfilling career as a top goal[2]. As to whether exposure to new ideas was a top goal, 83% of students and 88% of parents agreed that it was one. The message to engineering education faculty is clear - students rated highly the preparation for career fulfillment and the importance of critical thinking, while parents put great emphasis on the development of critical thinking. One way of elucidating to both students and parents how critical thinking is incorporated in the curriculum is to draw attention to the parallels between a key core requirement in the humanities - the learning of analogy, metaphor, and parable, and a key core requirement in math - algebra. Likewise, there is a need to develop a best practice approach in providing a clear explanation of these connections for prospective engineering students as well as for instructors who will present them in the classroom.

Critical thinking has been summarized as "an objective analysis of facts to form a judgment" on the popular website, Wikipedia. It is a straightforward description acceptable to most concerned parents of engineering students, and, more importantly, an easily understandable description for the beginning engineering student taking introductory calculus physics. From an entering student's perspective, the problem solving steps taught in algebra and calculus courses are often regarded as facts to be memorized and mastered through repetition. At the same time, judgment-forming skills are needed by students to compel them to think about examples and problems in a wider context.

Facts and memorization

There are many facts in physics for an engineering student to remember. The memorization of how free body diagrams are constructed to how integrals are to be implemented in problems concerning magnetism is already quite a challenge, but students need also to practice using judgment when they are presented with new examples and situations that require the linking of known facts with information given in a problem at the end of a chapter or a test. The laws of conservation and related formulas are easier for students to remember when they are compared to mathematical steps. It is the expression of the known facts as a series of mathematical steps that defines the central requirement of the objective analytical process. Among the various comprehensive assessment examples where the development of critical thinking in the second semester of calculus physics is prominent, is the Biot-Savart law. In this example, the vector cross product, embedded in the law, could be solved using basic trigonometry when the underlying symmetry is given, or with the 3-dimensional *i-j-k* vector notation system that is introduced in the first semester.

Many textbook authors have covered the Biot-Savart law example extensively. It is included in the free, online versions of Calculus Physics I and II offered by Open Stax [3, 4] and MIT [5, 6]. The magnetic field's magnitude and direction away from the symmetry axis of a current loop at (x, y, z) could be calculated by following the mathematical steps that use the 3-dimensional *i-j-k* vector notation system[7]. On the other hand, a rotation of the coordinate system such that the given (x, y, z) would become (x'= 0, y', z) would reduce the problem to that of calculating the magnetic field of a dipole at the origin in the y-z plane, since a current loop carries a magnetic moment similar to that of a magnetic dipole[8].

The 3-dimensional *i-j-k* vector notation system is usually covered in the first semester when torque and angular momentum are introduced. Intensive practice using the 3-dimensional *i-j-k* vector notation system would teach students how to transform a set of steps into a skill, similar to the way that practice in solving simultaneous equations in technology physics develops mastery of that skill. Further assessment of a student's progress in developing that skill could be conducted in the second semester when the student is asked to use integration to solve problems associated with the Biot-Savart law using *i-j-k* notation.

Making Judgments

The decision to apply the *i-j-k* vector notation system is practical in that it avoids having to rotate the coordinate system to achieve partial symmetry in the asymmetrical Biot-Savart case of a straight current-carrying wire and a current loop. The required mathematical steps using the *i-j-k* system have been described in a paper concerning a plasma investigation project[9]. In that paper, the authors presented the case of a current-carrying circular loop (the reference loop) located in the x-y plane together with a straight current-carrying wire intersecting the x-y plane at a distance r from the origin with an arbitrary inclination angle. Although the mathematical steps needed for the straightforward computation of the magnetic field can be accomplished by working out derivatives, performing the equivalent computations using direct integration would be useful to a student as a self-checking exercise. This is especially useful when the given inclination angle is fixed at a specific value, say, 30 degrees, which would lessen the cognitive loading on the student.

Li, et al. (Reference 9) state, "In a simple asymmetric configuration where steady state currents flow through a straight wire and a loop, a somewhat surprising feature is that the resulting magnetic field can become chaotic depending on the relative size of the currents." Even though the study of chaotic behavior is beyond the scope of introductory calculus physics, discussing the variability of the current magnitudes in the straight wire and loop can elucidate its relevance with regard to magnetic reconnection. Two moveable bar magnets would generate field lines that reconnect as the distance between them changed, and could be illustrated in a 2-dimensional hand sketch or 3-dimensional computer drawing. The current variation case would present itself as a challenging exercise and would demand sound critical thinking at the introductory calculus physics level.

Discussion

The Biot-Savart law example in this report is not unique in terms of critical thinking development. Other examples implemented by our faculty members, using facts learned across two semesters, include studying force and energy in the movable plate capacitor and their relationship to Faraday induction, and energy transfer in magnetic and non-magnetic ball collisions. Examples that can be covered in one semester include the study of internal forces when an inclined block into split into two pieces, and the study of electric potential and virtual ground in circuits. In any event, the maximum cognitive loading level that students would encounter in the course of developing critical thinking would be in the Biot-Savart law cases mentioned above. Exposing students to the *i-j-k* system with the aim of developing critical thinking offers advantages to those who take advanced level courses, especially for those interested in robotic engineering and 3-dimensional graphic programming. At some time in the next decade, it is likely that artificial intelligence will outperform humans when it comes to memorization skills. Whether the Bayesian decision-making paradigm employed by AI to surpass the GO champion would post a challenge for teaching physics critical thinking to engineering students.

The judgment-making process involved in the application of the *i-j-k* vector notation system in the asymmetrical Biot-Savart case of a straight current-carrying wire and a current loop may be perceived as a precursor to the conceptual understanding of magnetic reconnection at the introductory calculus physics level. This achievement would no doubt satisfy the college goal of exposing students to new ideas, the third top objective mentioned in the Money Magazine survey[2]. There are other examples of first semester concept failing to carry onto the second semester. Take Hooke's law as an example. The Stanford magnetic reconnection exercise, based on rubber band stretching and rearranging, has been used by us to discover that some community college engineering students had not mastered Hooke's law in their second semester of physics in such a way as to treat the spring extension variable as the entire spring length [10].

When judgement is verified by experiment multiple times, the judgment will then become a factual support for a standard practice or procedure. This iterative dynamic process of fact-judgment interaction is one of the foundation for learning with intent in a college setting, which is extended to the learning in life after graduation. To what degree students have learned a fact-judgment interaction would be assessable in problem solving. The following rubric, as seen in Table 1, has been developed to assess the fact-judgment process in solving a Biot-Savart law problem with written expressions instead of multiple-choice questions. A recent assessment paper on academic misconduct pointed out that open-ended written tests can simultaneously assess both analytic and communication skills, and may be selected by an instructor over multiple-choice examinations [11]. The learning and assessment of fact-judgment interaction will enhance multiple-choice question style assessment including the popular Force Concept Inventory assessment for engineering students taking first semester calculus physics with post-score relative to pre- score parameter

Table 1: Fact-judgment assessment rubric. The participants are students. Scoring could be performed when assigning Highly Competent = 1, Competent = 0.8 and Needs Improvement = 0.6.

Participant Deliverable	**Highly Competent**	**Competent**	**Needs Improvement**
Linking facts- vector representation *using the i-j-k* system (20%)	Provided a clear and correct assignment of the *i-j-k* system with the given geometry that facilitates calculation.	Provided a correct assignment of the i-j-k system with the given geometry but made one mistake.	Contained two or more mistakes in assigning the vector system
Judgment- Biot-Savart law cross product formulation (20%)	Provided a clear and correct Biot-Savart law cross product formulation according to the geometry in the problem.	Provided a clear Biot-Savart law cross product formulation but made one mistake.	Contained two or more mistakes in expressing the Biot-Savart law for the problem
Linking facts - evaluation of the cross product in each of the component (25%)	Provided a clear and correct evaluation of the cross product in each component.	Provided a clear evaluation of the cross product in each component but made one mistake.	Contained two or more mistakes in cross product evaluation

Linking Facts-integration in each component (25%)	Provided a clear and correct answer for the integration in each component.	Provided a clear answer for the integration in each component but made one mistake.	Contained two or more mistakes in integral evaluation
Judgment-graphical presentation of magnetic field (10%)	Provided a clear and correct graph capturing the essential features in each component.	Provided a clear graph capturing the essential feature in each component but made one mistake.	Contained two or more mistakes in graphing

Conclusions

Our aim in this paper is to share our experiences on the delivery of critical thinking as the linking of facts to establish a judgment. One may disagree with the Wikipedia explanation on "Critical Thinking" with reference to psychology. Another acceptable critical thinking explanation source could be from Stanford Encyclopedia of Philosophy: We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference… [12] " A deliverable on inference can be added to the above assessment rubric. An inference of Biot-Savart law could be an explanation of how a graph would change when an external parameter changes. Future pedagogy studies could include Bayesian-based AI systems for critical thinking delivery and enhancement of individual learning speed. The effect of critical thinking training on long term presynaptic plasticity in brain function and RNA localization could be another important future inquiry [13, 14, 15]. The issue of gender equality in spatial abilities could also be studied with exercises based on critical thinking using the vector system [16].

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