Pedagogy of Non-Inertia Frame Effect of Tidal Torque and Atmospheric Dynamics Models in Community College Research Experience Projects for Pre-Engineering Students

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Abstract: Hurricane and galaxy tidal effect are routine teaching topics in community college first year science courses, but there is a knowledge gap without a quantitative discussion of the physics of non-inertia frame. A survey of YouTube videos posted by Education Centers and professors showed that the hand-waving conceptual explanation is the most popular delivery pedagogy. We have eliminated the knowledge gap by developing a pedagogy of non-inertia reference frame effect for conceptual physics and introductory astronomy courses using knowledge transference from the contents in fluid mechanics. Science demands a conceptual foundation of reference frame if the extra math terms are not being treated as fudge factors. The reference frame effect must be introduced in early physics class Mechanics to prepare students for more subtle but important applications in Electromagnetism. An understanding of the reference frame effect is also needed for the presentation of the convective derivative, reference velocity in RANS fluid, etc. Nevertheless, the learning objective of programming skill in a computational project would not be affected by using either fudge factor effect or reference frame effect perspective. A method of using the result of a student computational project to assess the understanding of the reference frame effect versus fudge factor effect is proposed. The sustainability of the pedagogy with a discernment of the fudge factor effect (phenomenon-based pedagogy) versus reference frame effect (model-based pedagogy) in student computational projects in the post-COVID era is discussed. A Context-first pedagogy as a hybrid method is presented to facilitate the transfer of what faculty have learned in the research project delivery to become an assessment tool in the understanding of physics derivation in a classroom. Recommendations are presented.

Keywords: Non-inertia frame effect, Fudge factor effect, Reference frame effect, phenomenon-based pedagogy, model-based pedagogy, Context-first pedagogy

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Introduction (Current Situation Explanation)

We are faculty members in a community college physics department. We have been using the Force Concept Inventory FCI as an assessment tool in physics one mechanics emphasizing the usefulness of the inertial frame of reference. However, there are real life examples that the non-inertial frame of reference perspective is useful, from explanations of Hurricane motion in Florida to James Webb Space Telescope orbiting L2, an empty point in Space. The proposed pedagogy includes the numeracy of Pythagorean Theorem suitable for high school teachers interested in the teaching of real-life examples.

Hurricane and galaxy tidal effect are routine teaching topics in community college first year science courses, but there is a knowledge gap without a quantitative discussion of the physics of non-inertia frame. A survey of YouTube videos posted by Education Centers and professors showed that the hand-waving conceptual explanation is the most popular delivery pedagogy, to the best of our searching skill. Specifically, the pre-engineering students in our community college interested in orbital mechanics for space flight applications and atmospheric dynamics applications for ecology studies would need to understand the rotation induced non-inertia effect in terms of algebra if not calculus. Without a fundamental understanding of what rotation would add to a rotating observer, research experience student projects with the continuation of a 4-year engineering and science program education could be futile, regardless of the mastering of the operation steps of a software package for the calculation of tidal torques in astronomy modeling and/or Coriolis effect in atmospheric modeling.

We have eliminated the knowledge gap by developing a pedagogy of non-inertia reference frame effect for conceptual physics and introductory astronomy courses using knowledge transference from the contents in fluid mechanics, due to the easy visualization of fluid (Veritasium, 2017). The additional eastward speed of a northward drifting cloud from the Equator has been animated for easy visualization as well (Atlas Pro, 2018). The addition of a few algebraic equations was found to be sufficient for quantitative student projects with a pre-requisite of Physics I Mechanics, together with some programming skills.

On the one hand, a regular knowledge transference usually would entail a reduction of calculus to algebra and then to graphics with numeric information. This reduction of math details in engineering content is a common practice without any contradictions. On the other hand, the non-inertia rotational frame effect explained with a pseudo centrifugal force contradicts the Newtonian forces arising from an interaction between two objects. Such an apparent contradiction must be eradicated. The math essence of including more terms in an equation to solve a science mystery/question could mimic the culinary essence of including more cooking ingredients to increase the taste complexity. The validity of the extra math terms requires data verification, just like the taste complexity regarding food requires customer evaluation.

In addition, science demands a conceptual foundation of reference frame if the extra math terms are not being treated as fudge factors. In comparison, the end correction for resonance in an acoustic pipe is treated as a fudge factor in a community college setting, since the math requirement to understand the analysis results of Rayleigh and then by Schwinger (both Nobel Laureates) is beyond the community college courses, in sharp contrast to the derivation of the mass correction in the spring-mass period formula as a routine practice in first year calculus physics.

The reference frame effect must be introduced in early physics class Mechanics to prepare students for more subtle but important applications in Electromagnetism. Whatever is added to an equation would have an additional energy mechanism, and such a fundamental concept in Mechanics would foster the understanding of the Wheatstone-Bridge null measurement using a passive detector in Electromagnetism, etc.. An understanding of the reference frame effect is also needed for the presentation of the convective derivative and reference velocity formulation in Reynolds-Averaged Naiver Stokes RANS fluid, etc. Nevertheless, the learning objective of programming skill in a computational project would not be affected by using either fudge factor effect or reference frame effect perspective.

The difficulty of using the result of a student computational project to assess the understanding of the reference frame effect versus fudge factor effect could be partially solved by including the reference frame effect in at least three different contexts in the literature search section. The sustainability of the pedagogy with a discernment of the fudge factor effect versus reference frame effect in student computational projects in the post-COVID era is discussed

Method

In a tidal force project, computer programming students usually would prefer programming as a substantial learning objective in projects with tidal distortion effect. The visualization of the Coriolis effect in liquid for Physics 101 students interested in climate change and Astronomy students interested in planetary science is a necessary pedagogy for most engineering students as well. The learning of mechanism, phenomenon-based pedagogy versus model-based pedagogy is discussed in details. Finally, the context-first pedagogy is discussed in details.

Phenomenon-based Pedagogy (Fudge Factor)

A discussion of Chemistry pedagogy as a phenomenon-based pedagogy has been published by a physics professor in American Chemical Society Symposium Series (Vincent-Ruz, 2020). The University of Michigan Physics Department Vincent-Ruz asserted that “Chemistry discipline studies have showed that linguistically diverse speakers have difficult asking Questions (disciplinary engagement) and experience insecurity (negative affective engagement) when investigating and writing about phenomena”. It is obvious that Phenomenon-based

pedagogy needs language skill as well as simple math skills, and in physics, math skills such as the trigonometry value calculation skill in the Snell's law of refraction application to apparent depth understanding is expected.

The Phenomenon based pedagogy usually would require less math skills when compared to the Model-based pedagogy in the college level. The van der Waals force and electric dipole force are Coulomb forces in nature, but are treated as fudge factors in the equations of molecular dynamics simulation. For instance, a recent YouTube video on the use of a molecular drug to manipulate the vibration of a protein receptor explained the fudge factor application to the F = ma mechanism in Newtonian Physics (NanoRoom, 2023). Starting video frame 7:22, the video explained that doing a simulation is very much like doing an experiment. The simulation objective must be clear, the simulation controls must be designed carefully, and repeating the simulation many times is a must for evidence in the successful recreation of a studied phenomenon.

The Phenomenon-based pedagogy is favorable in introductory science courses. The Coriolis Effect in weather pattern has been illustrated by videos posted by the UK Government, and the video on Global Circulation has been used in our classes (Met Office UK, 2018), shown in Figure 1.

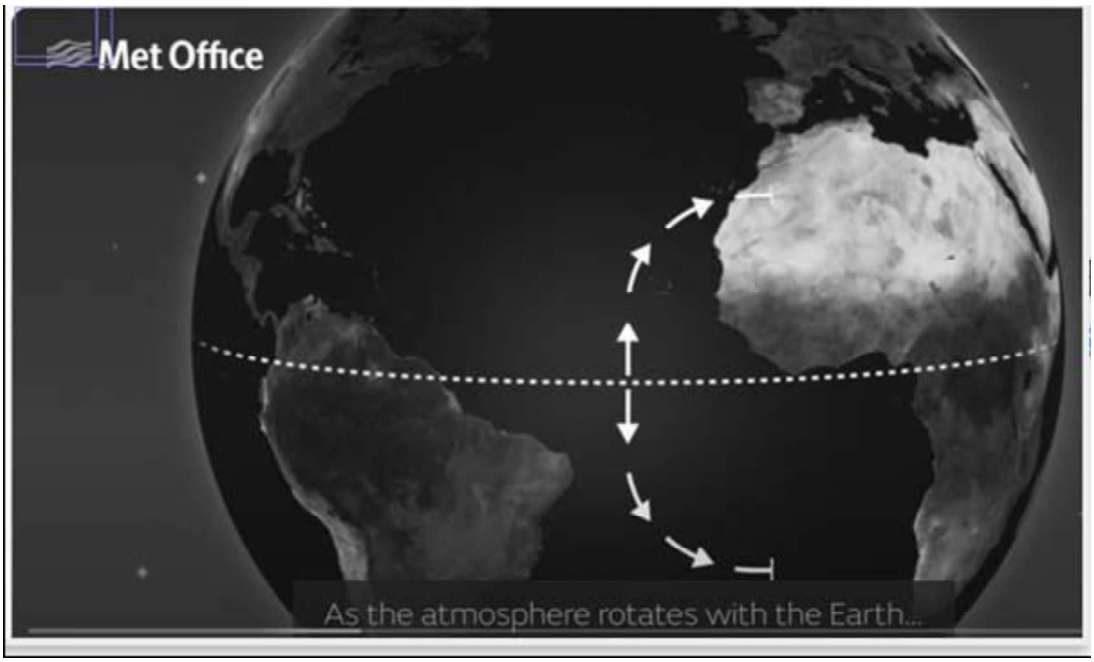

Figure 1. An Illustration of The Coriolis Effect, Adapted from The Met Office UK Video, https://www.youtube.com/watch?v=PDEcAxfSYaI, using ImageJ.

The tidal force effect in the Earth-Moon system has also been posted by a visualization professional (Merrell, 2018), and we have been using the clear animation in our Physics 101 and Astronomy classes, without the Euler's equations, shown in Figure 2.

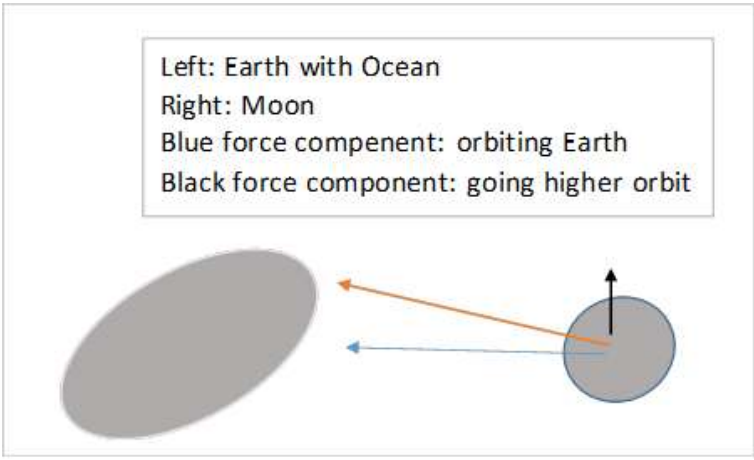

Figure 2. An illustration of tidal effect, adapted from Merrell: The Moon is Drifting Away https://www.youtube.com/watch?v=SqLzSlsrZZ4.

On the one hand, for easy calculation, the non- inertia frame centrifugal force is customary used to calculate the equatorial bulge or tidal elongation in celestial mechanics. On the other hand, conceptual physics presentation of the equatorial bulge could be presented in the following sequence. (1) The Earth and Moon have equatorial bulges. (2) The same centrifugal force concept applies to a spinning pizza dough to get a flatten structure. (3) The shift of center of gravity away from the center of mass allows a torque exerted by Earth to tidal lock the Moon spinning to reach zero torque, illustrated by Hewitt's video titled Ocean Tides, Figure 3 (Hewitt, 2012). The shift amount shown in Figure 3 is treated as a fudge factor in Phenomenon based pedagogy. (4) Earth spinning slows down and the radius of Moon must increase to maintain the conservation of angular momentum.

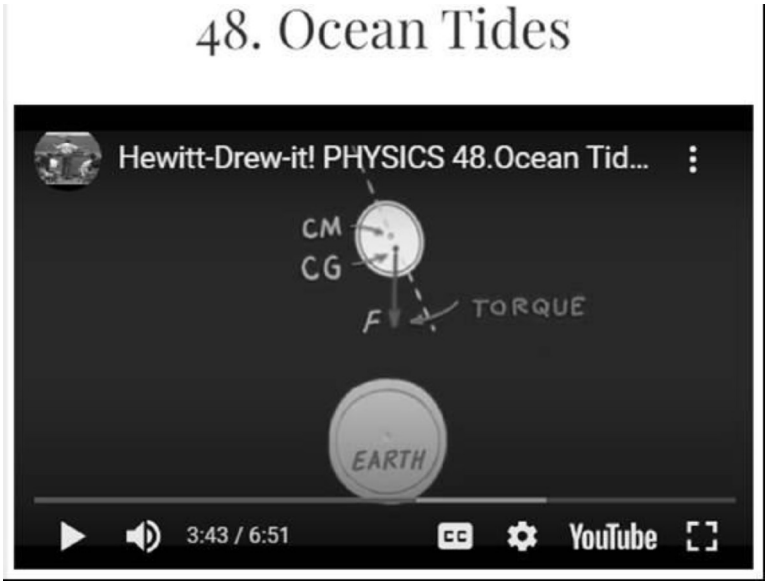

Figure 3. An illustration of the tidal torque, adapted from Hewitt Conceptual Physics video, http://www.conceptualphysics.com/41-50.html, using ImageJ.

Model-based pedagogy

The Model-based pedagogy shows the power of perdition, while the Phenomenon-based pedagogy has limited prediction.

The Model-based pedagogy of Coriolis Effect usually would start with Calculus chain rule. We found that the videos on Coriolis Effect by Dr. Ben Yelverton most helpful to our students. Calculus chain rule to derive the Coriolis Effect in rotating reference frame was presented concisely (Yelverton (a), 2021), with application to calculate the deflection of a falling particle (Yelverton (b), 2021), and the height for a significant Coriolis-induced deflection (Yelverton (c), 2021).

The Model-based pedagogy requires more calculus. We found that the materials provided by U of Texas Austin Richard Fitzpatrick to be very helpful to our students. The torque = moon mass*(-potential tangential change) to increase the Moon's orbital angular momentum, far more details than using force-arrows for torque in the Phenomenon-based model discussed above. The Earth's rotational equation of motion is I*Omega = (-torque), and by Conservation of Angular Momentum that an equal and opposite torque is applied to the Earth; the reaction torque in the model would act to decrease the Earth's angular momentum in spinning-rotation.

Context-first pedagogy

The ability of reading between the lines can be enhanced by inserting a hypothetical sentence to be placed in-between two (or several) sentences. The hypothetical sentence must be in the context of the already given sentences. These are the skills in literacy. The teaching of how to read between the lines can be called context pedagogy. Dictation is now replaced by voice to text technology in an office setting, so it is expected that AI would be able to read between the lines using statistical inferences; and students could use AI assisted guidance in good learning cases or poor cheating cases. Meanwhile we still have to teach the basic skill on how to read between two lines.

The filling of the missing information in the context of the preceding and following sentences is a standard practice. A similar practice can be extended to algebra expressions instead of English sentences. Students need to know the algebra substitution skill to fill in the missing derivation step so that the preceding step, fill-in step, following step are consistent with each other. The practice emphasizes on the consistency of the reasoning in the formation of a complete content. A collection of consistent sentences constitutes a content and the fill-in-the-blanks pedagogy is a well-accepted instrument. When the repeated calculations of a formula with different numerical values is called practice pedagogy, then a collection of algebra steps to represent the content of a formula could be called context first pedagogy.

A Context-first pedagogy first defines the circumstances on how a content (when completed) would relate to the

environment of other contents. In the context of algebraic substitution, model-based pedagogy is delivered. Wikipedia explains that “Cloze tests require the ability to understand the context and vocabulary in order to identify the correct language or part of speech that belongs in the deleted passages”. In our College, the asking of a single missing word in each sentence of an exercise/test is called "fill in the blanks" in Physics101 and Astronomy courses.

The extension to "Cloze test in symbols" in finding missing steps in algebra has been described by Khans Academy on YouTube (Khan Academy, 2014). A fill in the blank exercise could be used to assess the learning of the derivation of distance = v0t + 0.5*a*t*t after the teaching of how to combine the equations of distance = (v0/2 + vf/2) *t and vf = v0 + a*t, a derivation with standard notation shown on textbooks such as Open Stax College Physics 2e Edition. The symbols of “a” stands for acceleration, “v0” stands for initial velocity, “vf” stands for final velocity, and “t” stands for time interval.

The assessment of a derivation of Coriolis acceleration used by us is shown below, adapted from Jon Toellner’s video (Toellner (a) 2015). YouTube videos such as Python codes on angular momentum can be adapted for assessing an understanding of Python codes in Physics (Toellner (b), 2021)

Cloze test starts (r stands for linear distance, s stands for arc length, w stands for velocity in circular path)
We have r = v*t in linear geometry Lab 1 of Physics One
We have s = r*angle in circular geometry Lab 1 of Physics One
We have angle= w*t, common sense of displaced angle = angular velocity of a point on a wheel* time
Then s = _____ using substitution (answer v*w*t*t)
Then s = 0.5*(2*v*w)*t*t
Then a = 2*v*w, acceleration magnitude,
End

Taking one of above derivation step away will constitute a Cloze test, just like the Khan's Academy video. When the content is incomplete, there are expression in the contexts of linear motion (r = v*t), circular geometry (s= r* angle), and circular motion (angle = w*t in common sense daily life that a point on a wheel rotates a displaced angle determined by angular velocity * time in analogy to linear motion).

After completing the Cloze test, the completed content emerges, the content of Coriolis effect when the s-amount is the deflection to the East and r is the falling radial distance from a roof top towards the Earth Center (a building not on North Pole). Then the content delivery can use a drawing of a tall tower free fall, and show the directions without the (i-j-k) notation. Only when the students understand the context, defined by Merriam-Webster as the environment or setting that something exists or occurs, the content becomes clear.

The context language is not English, but algebra. Repeated calculation exercises of the Coriolis acceleration

with different numerical values would have missed the model-based pedagogy, since derivation understanding is one of the learning objectives in a Model-based pedagogy.

In the first week of Physics One, an instructor can do recitation emphasizing the algebra substitution in physics, with applications to hurricane swirling counter- clockwise in Northern Hemisphere, etc. The tidal force can be taught using the context first method when there are algebraic derivation steps. All calculus steps can be replaced by finite differences. The Context-first pedagogy aligns with environment awareness in terms of global warming, climate change, etc. In the context of algebra-based derivation, we put together the steps to transform a partial content to a full content.

In the first week of mentoring a research computational project in a community college setting, the algebra steps in the derivation of a formula can be replaced by the computer coding steps used in a published research paper. A context first approach ensures a student to understand the generality of the coding steps being applicable to the various models used in a celestial motion project, an atmospheric dynamics project, a climate change project, etc.

Results of the Pedagogy

The difficulty of using the result of a research computational project to assess the understanding of the reference frame effect versus fudge factor effect could be partially solved by including the reference frame effect in at least three different contexts in the literature search section N = 1 out of 3.

An assessment of research project students on the effective programming of the formulas with added fudge factor terms showed 3 students satisfactory passing, N =3

An assessment of astronomy students on the understanding of the tidal effect simulation video with force decomposing into 2 components, phenomenon-based pedagogy, that the Moon is moving away showed 5 students satisfactory passing, N = 15 (using Pythagoras theorem arithmetic for the force decomposition).

A similar assessment of conceptual physics students on the understanding of the tidal effect simulation video showed 8 students satisfactory passing, N =18. The equatorial bulge assessment using cloze test format showed N = 3 students satisfactory passing, N = 18.

An assessment of algebra physics mechanics students on the understanding of the kinematics s = v0*t + 0.5*a*t*t derivation cloze test, 11 students satisfactory passing, N = 18. With the same cohort, a Coriolis acceleration derivation cloze test, 6 students at satisfactory passing, N = 18.

Discussion

Tidal effect calculation has applications in solar system analysis, and the model based pedagogy could be delivered to students wanting a second course in astronomy.

The sustainability of the non-inertia frame pedagogy is supported by selecting YouTube videos, a well-accepted practice in post COVID era. We live on a rotating Earth. Students interested in atmospheric science, weather forecast, etc. need an understanding of the non-inertia frame, not to mention the Mach's Principle important to physics majors. The Nobel Laureate Weinberg regarded the Mach's Principle as one of the unresolved issues in Physics (Weinberg, 1972). In engineering, an inertial frame is a reference frame, for example, defined with respect to fixed distant stars, in which the rotating frame rotates (Tricoche, et al. 2021).

The mentoring of student research projects related to non-inertia frame effects can strengthen the faculty members in their abilities to adapt the pedagogy in research projects to classroom projects. Simple short projects like Python coding of angular momentum cases are suitable in a classroom setting, following the YouTube Toellner's video (Toellner, J. (b) (2021). There is always a need for non-inertia reference frame pedagogy, necessity of knowing orbital mechanics for space flight analysis (Wilmer, et al, 2024). In fact, the James Webb Space Telescope orbits around L2 has been explained on YouTube using a centrifugal force model at the Pythagorean Theorem calculation level, so is the case of Gaia Spacecraft orbiting L2 for parallax measurements (Ready, 2022).

Discernment of the fudge factor effect versus reference frame effect in student computational projects of atmospheric and tidal force effects increase authentic research experience in science. In other words, students knowing vector calculus could be mentored with the model-based pedagogy, while students starting in Python could be mentored with the Phenomenon-based pedagogy, fully in compliance with the DEI mission of our minority serving institution, and consistent with a report that Phenomenon based pedagogy was found to match with Model based pedagogy (Grusche, 2019).

The non-inertial frame perspective in conceptual physics discussed above is also a useful pedagogy for interested high school teachers. The numeracy in the Pythagorean Theorem is readily adaptable to the calculations of forces in terms of their components.

Conclusions

The non-inertia frame effect of tidal torque and atmospheric dynamics models could be delivered with the use of YouTube videos, popular in post COVID era. Using fudge factor concept for those students needing algebra improvement was found to be effective as an extension to the phenomenon-based pedagogy without the full implementation of model-based pedagogy

Recommendations

The tidal force and Coriolis acceleration should be included in Physics One, using cloze test to assess algebra derivation, while the Phenomenon-based pedagogy is applicable to Conceptual Physics101 as well. The James Webb Space Telescope and Gaia Spacecraft orbit around L2 in the centrifugal force model shown on YouTube at the Pythagorean Theorem calculation level should be included in astronomy pedagogy, and also would be suitable for interested high school teachers to implement in their classes.

The Context-first pedagogy could help those students who are failing in the Model-based pedagogy, when using the fudge factor perspective to continue the homework assignments

The mentoring of student research projects related to non-inertia frame effects will strengthen the faculty members in their abilities to adapt the pedagogy in research project to classroom projects, and therefore, should be recommended.

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