# Pedagogy Of Oscillation in Physics Using Control Theory Eigenvalue Stability with Extension to Oscillation Without Physics in Post-COVID Era

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**Abstract**: The damped harmonic oscillator physics problem is a standard oscillation problem in calculus physics for pre-engineering students in a community college. The use of alternative linear algebra eigenvalue stability method is consistent with the upper engineering courses using control theory. The external force and friction damping would become the control and feedback respectively in control theory. The objective of quantifying stability has wide applications from Lego to Arduino driven educational robotic systems in mechanical engineering student projects. The IllustrisTNG galaxy simulation data and the Skynet Robotic Telescope Network Supernova data are also open-source data for student projects taking on the stability studies. The equity of authentic experience in the outcome of each student would require differential-unequal input conditions across the cohort of students every year. An extension to oscillation without physics is mathematically justified when the studied system could be represented as two coupled linear first order differential equations. All the teaching contents were extracted from the open sources posted on the websites of leading university professors and professionals. The eigenvalue pedagogy is also ready for the online delivery of student skill learning projects in the post-COVID era, given a community college setting. The assessment has been conducted with the what-if critical thinking perspective. The sustainability of the eigenvalue pedagogy in community college student skill learning projects in the post-COVID era is discussed, together with this transfer-enhancement pedagogy. Recommendations are presented.

**Keywords:** Eigenvalue stability, Oscillation, Engineering experience, Transfer-enhancement pedagogy

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## Introduction

Queensborough Community College (QCC) has Engineering Technology and Physics Departments. Two of the difficult questions from students have been "What is engineering?" and "What is the job opportunity?" We in the Physics Department have been developing a pedagogy to show "What is engineering?" given a limited budget and a requirement of online-ready in the post-COVID era. High school science teachers could fast forward to the Recommendation section to determine the applicability of the reported pedagogy in their high schools.

The solving of two simultaneous linear equations in high school algebra can be extended into the solving of the 2-coupled first order linear differential equations in the damped harmonic oscillator physics problem, which is a standard oscillation problem in calculus physics for pe-engineering students in a community college. The alternative linear algebra eigenvalue stability method is consistent with the upper engineering courses using control theory. The external force and friction damping would become the control and feedback respectively in control theory. The pedagogy of using the control theory notations in the standard damped harmonic oscillator problem would provide a seamless transition for pre-engineering students and a better understanding of the requirement of linear algebra in the transfers to senior colleges, a pedagogy for transfer enhancement.

The objective of quantifying stability has wide applications from Lego to Arduino driven educational robotic systems in mechanical engineering student projects. The stability of circuit is also a worthy education objective in electrical engineering student projects, although less obvious when compared to other objectives in circuit projects, notwithstanding the energy grid stability study project s during space weather events. The IllustrisTNG galaxy simulation data (IllustrisTNG, 2024) and the Skynet Robotic Telescope Network Supernova data (Skynet, 2024) are also open-source data for student projects taking on the stability studies. In fact, some of the TNG mocked images from simulation have been used in classrooms (Mihos, 2023).

The equity of authentic experience in the outcome of each student would require differential-unequal input conditions across the cohort of students each year. The math derivation ability of the student cohort was observed to be a steady decline over the years. The steeper decline of math derivation ability from the 2020 Lockdown was alleviated partially by using AI as a tool. The computer assisted linear algebra computation from Excel to Matlab was found to be invaluable to achieve equity in the authentic experience outcome given the diversity of students in a community college, from motivated high school students in our Outreach mission to open admission high school graduates in our degree programs across the STEM curricula. A systematic pedagogy has been developed with two steps. (1) A game of finding the hidden two numbers when the sum and product are given at the third-grade level, (2) An exercise to find the trace and determinant values of a companion matrix in the stability study of a damped harmonic oscillator at the college level. The eigenvalue pedagogy would satisfy three authentic experiences. (1) The applied math experience in the engineering experience pedagogy, (2) the engineering technology experience in assembling/building using components, (3)

the engineering science experience in the what-if critical thinking skill when the objective of a study is on an engineering parameter with its functionality.

The eigenvalue pedagogy can serve as a complementary component in all the hands-on student projects based on engineering (Level Two classification in the Method Section). An extension to oscillation without physics is mathematically justified when the studied system could be represented as two coupled linear first order differential equations (Level Three classification in the Method Section).

All the teaching contents were extracted from the open sources posted on the websites of leading university professors and professionals. The eigenvalue pedagogy is also ready for the online delivery of student skill learning projects in the post-COVID era, given a community college setting.

## Method

There are three levels in the learning of stability. The first level is based on a quick start of the learning of the matrix notations in control theory, based on first semester physics. The second level is the application of the eigenvalue stability method. The third level is to be informed that there are oscillations without physics. These three levels complete the learning objectives of a community college student project, from an undergraduate research project to a skill-learning high school project.

The YouTube materials from leading institutions are becoming mainstream in the post-COVID era under the supervision of professors in an open-admission community college, in our case the Queensborough Community College (QCC) in New York City. The YouTube videos by the top professionals are guaranteed to be videos of high authenticity. Together with the explanation an instructor, topics such as aerospace engineering, with 8% job growth rate according to the US Bureau of Lab Statistics 2022-3032, would be beneficial to students interested in jobs with higher growth rate.

The high school students in our Outreach mission could be taught at Level 1, the QCC engineering technology could be at Levels 1 and 2, and the Tristate CT-NJ-NY selected students in our NSF-REU program at QCC could be using all three levels. Practical stability issues encountered in QCC projects such as CubeSAT, NACA airfoil, telescope mount, etc. would include stability study. For physics projects using IllustrisTNG galaxy simulation data and the Skynet Robotic Telescope Network Supernova data, the stability studies have been limited to software simulations without the understanding of the mechanism captured by the related partial differential equations taught at senior colleges. Therefore, the understanding of stability in control theory will ensure a minimum scholarship in a stability study in applied physics.

## Control Theory State Space Representation using Matrix Notation (Level One)

The topic of a damped harmonic motion is standard in Physics One Mechanics. The standard differential

equation is displayed with usual variables, the symbol □(t) represents the position, the symbol □ represents the torque coming from mg*sin(□(t)) component, and c represents the coefficient of the damping torque at the anchor. A diagrammatic illustration of using the perspective of the control theory approach is shown in Figure 1. The diagrammatic drawing was adapted, with a different damping coefficient of 0.25, from the YouTube video put up by Dr Christopher Lum of the University of Washington (Lum 2018). The friction term is modeled as a feedback mechanism, while the external torque □(t) is modeled as a control variable. The control theory block diagram serves as an input example in the Matlab/Simulink solution, demonstrated by Lum.

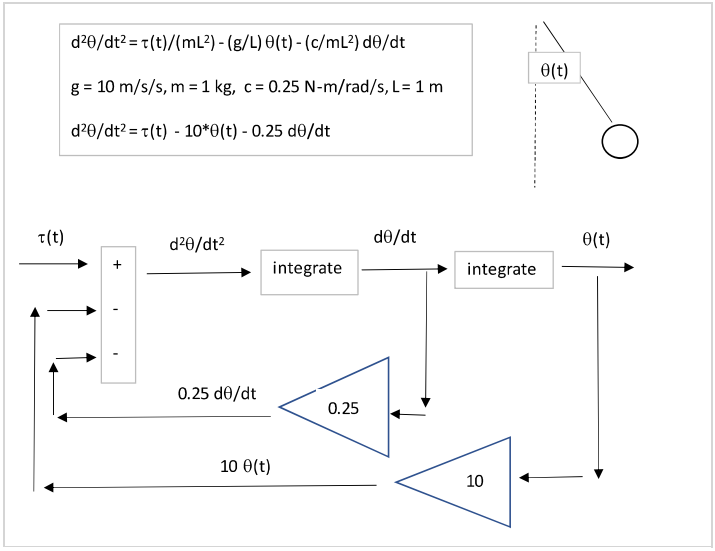


Figure 1. A Diagram Showing the Control Theory Perspective of a Pendulum With Damping.

The State Space linear algebra approach was also illustrated in the Lum's video. A summary is shown in Figure 2. The associated block diagram for Simulink simulation is shown in Figure 3.

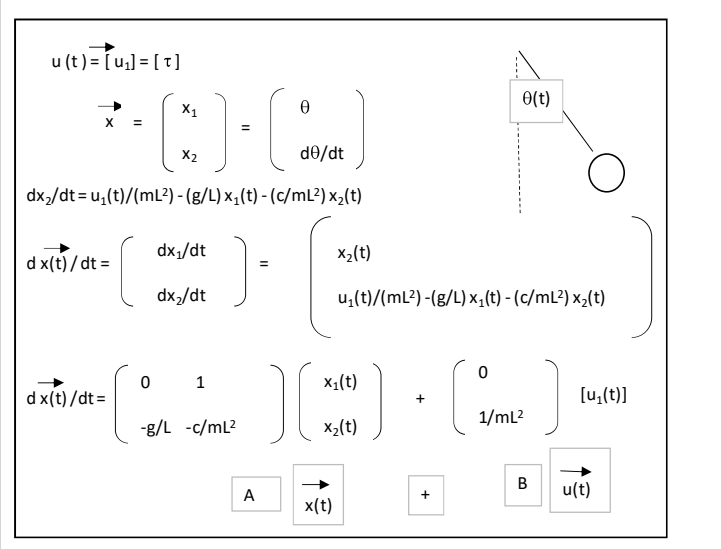


Figure 2. A Diagram Showing the State Space Model of a Pendulum with Damping.

Basically, the second order differential equation model, a popular physics approach, is transformed into two first order differential equations represented by matrix notation, a popular control theory approach. The above representation is our Excel summary version of the matrix content of the Lum's video, for illustration to our students.

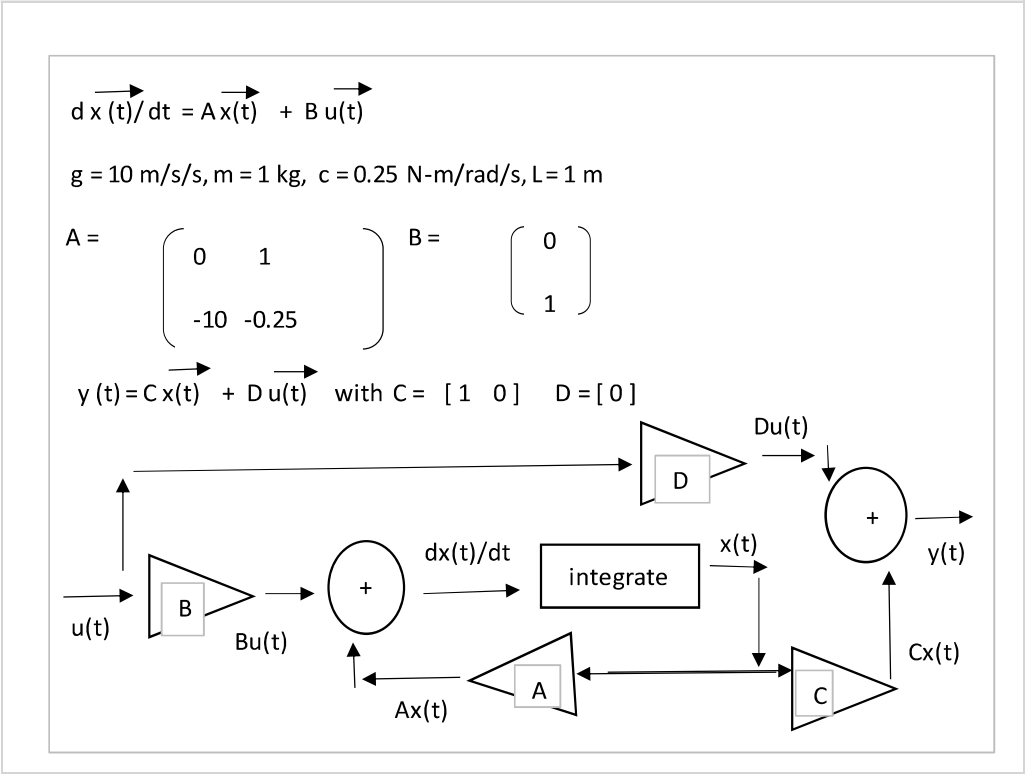


Figure 3. A Diagram Showing the State Space Block Diagram Model of a Pendulum with Damping for Simulink Simulaton, Variables Are from Figure 2.

**Application of the eigenvalue stability method (Level Two)**

The Linear Algebra course is usually taken by students after Calculus One for introduction, Calculus Two for infinite series, and Calculus Three for vectors and Calculus Four for differential equations. The eigenvalue stability pedagogy was based on the YouTube video of Professor Gilbert Strang of MIT using the 2 by 2 matrix example (Strang (a), 2016). For instance, the trace of a matrix with its associated determinant and the companion matrix of a differential equation are the Linear Algebra fundamental concepts, which are beyond the matrix notation for representing a system of simultaneous linear equations. A second YouTube video by of Professor Steve Brunton of University of Washington using the "N by N" matrix example has been helpful (Brunton, 2023).

Professor Strang explained that linear algebra matrix computation supports both probability/statistics and

optimization to perform deep learning algorithm with a learning function representing the evolution of the input matrices (Strang, 2018). A simple Kalman filter matrix exercise, useful in motion estimation for stability inquiry has been posted on YouTube, together with a Kalman filter arithmetic iteration exercise in temperature estimation (Biezen, 2016; Biezen, 2015)

**Oscillation without physics (Level Three)**

The MIT open-source lectures of Dr. Mobolaji Williams showed the well-known Prey-Predator model as an example of oscillation without physics in a summer research class for high school students (Williams, 2017). Since then, there are at least two YouTube sources with better explanation in our opinion. The video on "Divergence and curl: The language of Maxwell's equations, fluid flow, and more" explained the calculus notation with extension to the Prey-Predator model (Sanderson, 2018). The YouTube video on "Teaching dynamics to Life Science Student" used the State Space model to by-pass the complex calculus is another example of oscillation without physics (Garfinkel, (a) 2024). For engineering and physics students, it is essential to trace the 2 coupled first-derivative equations in the prey-predator model back to the single second-derivative equation in the damped harmonic oscillator model. Using Calculus Taylor Series expansion around an equilibrium point, with derivative terms set to zero, the damped harmonic oscillation differential equation would emerge (Garrett, 2012).

## Results of the Pedagogy

A QCC cohort, 5 students out of 19 students, Physics One course, were assessed at satisfactory passing, in the control theory perspective of the damped harmonic oscillators (Level 1).

The Tristate NSF-REU recruited community college students, 3 students out of 3 students were assessed at satisfactory passing Level 2 (paid with NSF stipends)

The aerospace engineering video contents were preferred by QCC college engineering students, 5 students out of 19 students were assessed at satisfactory passing, Physics One Mechanics Course Level 1 Matlab)

The Kalman filter arithmetic iteration exercise for temperature estimation were assessed with 6 students satisfactory passing, N = 19, Conceptual Physics 101, following the YouTube example but with a different set of input values (Biezen, 2015)

The high school students in a Physics One class were accessed at 1 student satisfactory passing, N =2, on the prey-predator model pedagogy. Both students understood the Level 1 Matlab, but did not understand Level 2 eigenvalue.

The high school students in physics research projects were interested in Level 3 prey-predator model directly, but not the control theory pedagogy. There were 5 high school students, N = 14, satisfactory passing in the Level 3 prey-predator model at the simulation operation level (Matlab-Python-Excel), with the task of changing a parameter and examining the new results.

We have observed that the studied high school students were influenced by a recent trend that the learning of calculus is not useful for the Life Science students, seen in the "calculus from hell" slide inside the UCLA video of "Teaching Dynamics to Life Science students at video frame 12:49" (Garkinfel (a), 2024. Instead another UCLA video of "Teaching Dynamics to Biology Undergraduates" advocated the trend of using Python to solve the equations in the study of dynamics systems (Garkinfel (b), 2024), with an accompanying article (Garfinkel, et al. 2022)

Over the years since the COVID Lockdown in 2020, about 50% of our recruited high school students in projects were interested to learn oscillation in the context of medicine, hence wanting the "oscillation without physics" in the Level 3 pedagogy directly without Level 1 Matlab control theory knowledge and Level 2 eigenvalue stability knowledge. We found that the 3-coupled first-derivative equations for the hypothalamus-pituitary-gonad feedback system illustrated by the UCLA video of "Newton Abraham Lecture video frame 29:41" would be sufficient to learn about oscillation without physics, skipping the learning of control theory in Level 1 and eigenvalue stability in Level 2 (Garfinkel (c), 2022). We also found that the 2-week extra credit short projects at Level 1 state space representation and/or Level 3 prey-predator model have been be popular for premed students taking Physics One.

There are traditional pedagogies to support the concept that a community college is an extension from high school for the AAS-degree students with job seeking priority. One of the most important results in the stability pedagogy reported in this article is to remind faculty members in community college setting that there is a new pedagogy to show the continuation to a third-year syllabus. In addition, the stability pedagogy can clarify "what is engineering" to the calculus physics AS-degree students (15%) among the algebra physics AS and AAS students (85%) in the context of physics learning.

In our limited experience, we found that the student group with top 20% ranking before the Lockdown was gone from our community college in this post-COVID era. We attributed this phenomenon to the senior colleges in our CUNY System using their administration flexibility to adjust their admissions when compared to our open admissions. The feedback to the faculty mindset includes a satisfaction that we are doing the best we can with an implementation of a new pedagogy on teaching the stability concept to help our students to contiune their education in this post-COVID era. The result of faculty mental satisfaction is a surprise, not that we have psychological data to quantify our mental stability in having satisfaction in this post- COVID era with the new issues including challenges of 70% enrollment, less prepared students, job versus transfer comparison upon students' requests, etc.

## Discussion

The University of Washington Christopher Lum's and Steve Burton's aerospace engineering videos on YouTube have been used because they provide links to many other videos on various aerospace engineering topics. The videos contain the topics of wind tunnel, flight parameters, etc. that we have used as guides to answer the students' question of "what is engineering". In particular, the eigenvalue stability videos in the application examples illustrate the engineering context in linear algebra, a math requirement of Grove Engineering School of City College of CUNY for our QCC transfer students.

Using the Greek symbol tau for torque instead of the T- symbol in the Lum's video was found to help the bottom 30% students who were uncomfortable in algebra manipulation.

The need for pre-engineering students to maintain interest in linear algebra sustains the rationale of using the eigenvalue stability pedagogy in oscillation physics. The single value decomposition matrix method in linear algebra is also used to study accelerator orbit stability in accelerator engineering physics, but none of our 3 physics majors knowing calculus were interested in accelerator engineering physics as of September 2024.

Faculty members would need to be flexible and get ready to deliver one of the 3 Levels (Matlab control theory, eigenvalue, oscillation without physics) as an independent topic, given the student interests variation in a DEI community college setting.

We have learned a valuable lesson from our QCC CubeSAT project experience. The QCC CubeSAT project, using the equipment and student stipend supports from the QCC-NSF-REU grants (PI Lieberman), was part of the CUNYSAT-1 Program led by the late Professor Shermane Austin of CUNY Medgar-Evers College (she sadly passed away 3 months ago). The 1U CubeSAT was launched but no signal was received (Gunter, 2013). The CUNYSAT was launched from Vandenberg Air Force Base on December 6 2013 (NASA LSP, 2013). In retrospect, the QCC students' authentic experience, (Shekoyan, et al. 2009), could have been supplemented with a more detailed CubeSAT stability study, similarly to the tumbling block stability method at low budget level (Strang, (b) 2016). The CubeSAT mission passed all the launch-protocols with the mission of the science of ionosphere disturbances, presented by QCC physics faculty mentors Tremberger and Cheung at Goddard Institute for Space Studies, Columbia University. A study of CubeSat stability in 2024 would not be sufficient to start a project, but a final CubeSAT product cannot violate stability regardless of the mission. The tumbling instability of the Advanced Composite Solar Sail System (ACS3) with a mission of solar sail testing on a 12U CubeSAT is still confronting the NASA ACS3 team as of October 22 2024 (NASA ACS3, 2024)

A stability inquiry would serve as an additional learning objective in a drone project. For instance, a drone/helicopter payload modeled as a pendulum would satisfy the criteria of an engineering physics research project in dynamical system, when using another drone for data collection. A chamber with reduced air pressure

would enable flight stability study in a Mars-like atmosphere. The method of "PocketLab Voyager 2 as a payload on DJI Drone" has been used in kinematics pedagogy (Young, et al. 2024), and would be readily deployable as equipment in engineering physics research projects. Our QCC Outreach College Now Program has a budget to support equipment for the high school students in engineering physics research projects, and yet none of the enrolled high school students were interested to continue their education in our QCC degree programs so far, based on our physics department enrolment data. The physic department faculty members could transfer the College Now teaching experience to the teaching of the degree-students in our DEI community college courses.

The stability pedagogy could be extended to include stability of rocket using fins in engineering studies, plasma instability in astrophysics studies, inertia confinement fusion studies, etc. Such extensions can be started when using the Kalman Filter technique as an academic learning outcome. The Kalman Filter on the motion and measurement models can be used to demonstrate Machine Learning in terms of Control Theory, illustrated on a YouTube video by Professor Jonathan Kelly, University of Toronto (Keller, 2021). The embedded Kalman filter using the MPU6050, a 3-axis gyroscope and a 3-axis accelerometer on a silicon chip, was illustrated on YouTube with Matlab codes by Professor Tom Moir, Auckland University of Technology (Moir, 2021)

The SpaceX rocket technology in which rockets can return to their launch pads has been a popular topic in students' discussion. The advanced thrust vector control rocket with Kalman Filter is a distant project due to an observation that there is a need of a relatively large budget to accommodate a few failed launches in the beginning when using the thrust vector rockets available in the hobby market (BPS.SPACE, 2024). The timing-loop demand on the flight control of thrust vector rocket without rocket-fins would constitute an authentic skill learning experience on the Kalman Filter technique. A tutorial video on thrust vector control assembly emphasized that the rocket stability control by the Kalman filter technique can be reduced to an activity of copying codes without the need to understand the matrix representation of the motion and measurement models (Thornhill, 2022).

It is important to include future extensions in a discussion. The Lum's aircraft dynamics videos on YouTube can be extended with YouTube videos on rocket technology. The OpenRocket simulator with its output flight data as inputs to Matlab for a calculation of the forces have been implemented by MIT students (MIT Rocket Team, 2019). The addition of roll, pitch, and yaw parameters using Matlab in an extension of OpenRocket Simulator has been demonstrated in a YouTube video (Lafayette System, 2024), and can serve as an example of an extension of the roll-pitch-yaw of an aircraft.

The DIY rocket projects on "Autodesk Instructables" is within the budget of a community college (Autodesk Instructables, 2024), but the hands-on exercises in extra- curricular activities could raise liability issues for faculty members in a community college setting, unlike other colleges with relative large budget. For instance, the RIT Launch for student clubs at Rochester Institute of Technology have been launching rockets built by

students. In fact they host a YouTube tutorial video on "Basics of OpenRocket" (RIT Launch Initiative, 2021).

The NASA paper rocket project (NASAJPL Edu, (a), 2020) and paper Mars helicopter project (NASAJPL Edu, (b) 2020) would be a first level learning, with a second level learning using the NASA foam rocket project. These hands-on projects are very effective as authentic experience, and can be upgraded to national standards like the projects funded by NSF-REU when including a stability investigation as an academic standard, deliverable by using the OpenRocket Simulator, Matlab, etc.

## Conclusions

We found that the study of oscillation in physics would provide a pedagogy to introduce the concept of stability in control theory, which is important for community students to acquire some authentic experience in "what is engineering". The Level 2 of eigenvalue stability was found to be deployable in Physics One Mechanics class. The 2-week extra credit short projects at Level 1 state space representation and Level 3 prey-predator model was found to be popular for premed students taking Physics One. We found that Python would be a viable computational tool, but Matlab is easier for QCC students having free access already.

## Recommendations

Oscillation and stability related projects would show a continuation to the Third-year engineering programs, such a transfer enhancement pedagogy would enhance retention of community college pre-engineering students.

In the pedagogy of state space model and prey-predator model, the computational skill development is an important learning objective. For those students doing the 2-week extra credit projects, it is important to show the students that skill development could be classified as a synergy of the following: (1) rote learning of basic skills with feedbacks for better practice, (2) using a selected standard as a reality check to evaluate progress, (3) aligning objectives to be compatible with a given environment to keep up the aspiration and time investment.

Faculty members need to be flexible to foster the learning of stability in terms of (1) Matlab/Python computations, (2) eigenvalue stability, and (3) oscillation without physics as an independent topic regardless of eigenvalue stability, due to students' diverse background in a community college setting, including high school students taking college courses.

High school science teachers could use the UCLA videos of Professor Garfinkel, discusses above, to guide their students who are interested in life science and biology to study the prey-predator model with oscillation, but without physics.

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