

A rational mechanics course where everything is made with Python code

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New Media Pedagogy 23: research trends,
methodological challenges and succesful
implementations

21-24 november 2023



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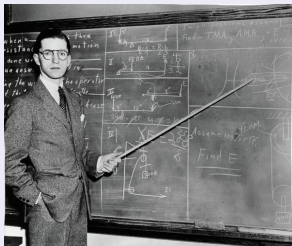
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Value students and professors time

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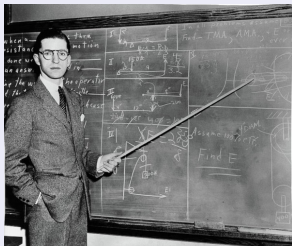


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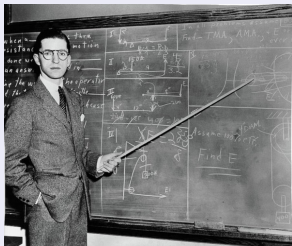


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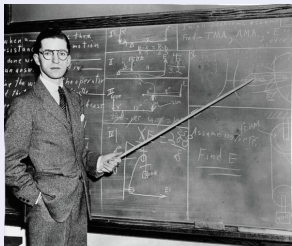


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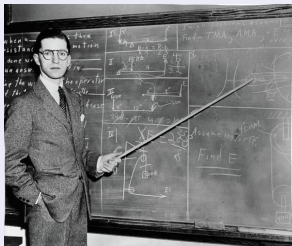


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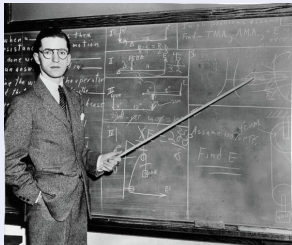


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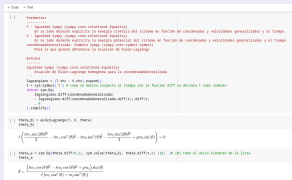
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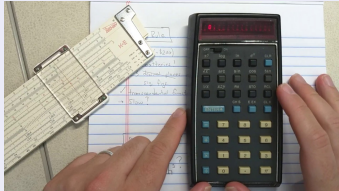
Digital course material with embedded code

- Professor: ideas $\xrightarrow{\text{updates}}$ code/theory in repository

Engineering students can take advantage of code at every single lecture

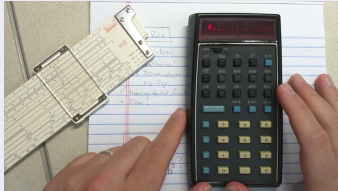
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- Now they'll employ computational algebra **after they learnt** algebra and calculus



```
[14]: sistemaEcuaciones = [  
      x_EL,  
      phi_EL,  
    ]  
variablesDespeje = [x.diff(t,2), phi.diff(t,2)] # despejar aceleraciones generalizadas  
variablesDespeje_sol= sym.nonlinsolve(sistemaEcuaciones, variablesDespeje ).args[0]
```

```
[15]: x_pp = sym.Eq(variablesDespeje[0], variablesDespeje_sol.args[0] ) # [m s-2]  
phi_pp = sym.Eq(variablesDespeje[1], variablesDespeje_sol.args[1] ) # [m s-2]  
x_pp, phi_pp
```

$$[15]: \left(\begin{array}{l} \ddot{x} = \frac{-\ell g m_2 \sin(\phi) + \frac{\ell m_2 (\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{m_1 + m_2 \sin^2(\phi)}}{\ell m_2 \cos(\phi)}, \ddot{\phi} = -\frac{(\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{\ell (m_1 + m_2 \sin^2(\phi))} \end{array} \right)$$

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 - ▶ Employing numerical calculus they solve what is impossible in a blackboard/paper



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Papert (1980) “...the best learning takes place when the learner takes charge”

- An example problem is solved by the professor provided code
- The student **recycles** it to solve other related problems
- Gradually becoming autonomous by reusing not the provided but his own code

Tools — Jupyter notebook: text + equations + executable code

The screenshot shows a Jupyter Notebook window with the title "PÉNDULO ENHEBRADO SOLVED.IPYNB". The left sidebar contains a table of contents with the following items:

- Péndulo enhebrado en aro
- Enunciado
- 1. Construya el Lagrangiano y la(s) función(es) de ligadura
- 2. Calcule las ecuaciones de Euler-Lagrange
- 3. Obtenga una expresión para la tensión que ejerce la barra
- 4. Grafique la tensión en los primeros diez segundos de la dinámica.

The main content area displays the following text and code:

3. Obtenga una expresión para la tensión que ejerce la barra

$$Q_d = \lambda_1 \frac{\partial f_1}{\partial d} = \lambda_1$$

Por tanto hay que resolver el sistema con las 3 ecuaciones de Euler-Lagrange y la única de ligadura para determinar λ_1 . Esta última hay que resolverla para su caso homogéneo y expresar su derivada segunda para que esté en el mismo orden que las de Euler-Lagrange, a fin de cuentas estamos resolviendo sistemas diferenciales de 2.º orden.

```
[14]: f_1
```

$$f_1 = -l + d$$

Determinamos también $\ddot{\theta}_1$ y $\ddot{\theta}_2$ pues serán necesarias para los cálculos numéricos posteriores.

```
[15]: sistema = [theta1_EL.expand(),
               theta2_EL.expand(),
               d_EL.expand(),
               sym.Eq(f_1.rhs.diff(t,2), 0), # esto es igual a d punto punto = 0
               ]
variables = [theta1.diff(t,2), theta2.diff(t,2), lambda_1]
variables_sol = sym.nonlinsolve(sistema, variables).args[0]
```

```
[16]: lambda_1_sol = sym.Eq(lambda_1, variables_sol.args[2])
      lambda_1_sol.simplify()
```

```
[16]:
```

$$\lambda_1 = \frac{m \left(2a \cos(\theta_1 - \theta_2) \dot{\theta}_1^2 + g \cos(2\theta_1 - \theta_2) + g \cos(\theta_2) + 2d\ddot{\theta}_2 - 2\ddot{d} \right)}{\cos(2\theta_1 - 2\theta_2) - 3}$$

Tools — Google Colaboratory runs Jupyter notebooks on-line

- The platform allows professors to edit and comment on the work of students.
- Students can collaborate remotely, working on the same Jupyter notebook.

The screenshot displays a Google Colaboratory Jupyter notebook. The top bar includes the Google Colab logo, the notebook title "07 No conservativas | ej4", and navigation links like "Archivo", "Editar", "Ver", "Insertar", "Entorno de ejecución", "Herramientas", and "Ayuda". On the right, there are buttons for "Comentar", "Compartir", and a user profile icon.

The notebook content is divided into two main sections. The first section, titled "+ Código", contains a Jupyter code cell with Python code using SymPy for symbolic computation. The code defines variables for a physics problem involving a spring and a pendulum, calculates potential energy, and defines a Lagrangian. Below the code, the resulting mathematical expression for potential energy is shown:

$$V = gm_1(-l_{10} - x_1)\sin(\theta) + \frac{k_1(l_{10} + x_1)^2}{2} + \frac{k_2(l_{20} + x)^2}{2}$$

The second section, titled "Lagrangiano", contains another code cell that defines the Lagrangian L as the difference between kinetic energy T and potential energy V . Below the code, the resulting Lagrangian expression is displayed:

$$\mathcal{L} = -gm_1(-l_{10} - x_1)\sin(\theta) - \frac{k_1(l_{10} + x_1)^2}{2} - \frac{k_2(l_{20} + x)^2}{2} + \frac{(m_0 + m_1)(2\cos(\theta)\dot{x}\dot{x}_1 + \dot{x}^2 + \dot{x}_1^2)}{2}$$

Below the Lagrangian, the text "ECUACIONES DE EULER" is visible, followed by a section titled "Para x".

On the right side of the notebook, there is a comment thread. The first comment is from Victor Alexis Bettachini, dated May 31, 2021. The comment discusses the physical interpretation of the spring constant k_1 and the sign of the potential energy terms.

At the bottom of the notebook, there is a footer area with the email address "vbettachini@unlam.edu.ar" and a "Para x" label.

Tools — All course material in a GitHub repository

- Clearly organised, freely accesible, and easy to update.
- Google Colaboratory loads Jupyter notebooks directly from GitHub.

The screenshot shows the GitHub interface for the repository 'bettachini / UNLaM_MecanicaGeneral'. The repository has 1 pull request, 0 issues, 0 stars, and 0 forks. The 'Code' tab is selected, showing a file list for the 'master' branch. The file list includes folders for slides (00Generalidades to 11RotaciónEuler) and various physics topics (01Newtoniana, 02NoInercial, 03Energia, 04EulerLagrange, 05Simulación, 06FuerzasLigadura, 07NoConservativas, 10TensorInercia, 11RotaciónEuler). The 'About' section on the right describes the repository as a collection of materials for the 'Mecánica General' course at the Universidad Nacional de La Matanza. It also includes tags for 'physics', 'mechanical-engineering', 'fisica', 'mecanica', 'lagrangian', 'vibrations', and 'mechanics-of-solids'.

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bettachini slides erste 3167a56 yesterday 188 commits		
00Generalidades	parcial retrasado	last month
01Newtoniana	09TensorInercia update	2 days ago
02NoInercial	cc by-nc-sa	last month
03Energia	cc by-nc-sa	last month
04EulerLagrange	Atwood compuestas	16 days ago
05Simulación	09TensorInercia update	2 days ago
06FuerzasLigadura	09 update lpyngo	4 days ago
07NoConservativas	07NoConservativas noConservativasEjemplos.lpynb	16 days ago
10TensorInercia	10TensorInercia lpynb update 2	2 days ago
11RotaciónEuler	numbering	2 days ago

About

Repositorio de la asignatura "Mecánica General" de la carrera de grado en Ingeniería mecánica de la Universidad Nacional de La Matanza.

physics mechanical-engineering fisica
mecanica lagrangian vibrations
mechanics-of-solids

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Releases

No releases published
Create a new release

Tools — From the 1st class — L^AT_EX: concise mathematical notation

- L^AT_EX typesetting follows strictly the standards of the American Mathematical Society

Considero que el potencial V es nulo en el origen de coordenadas, es decir que donde se encuentra su mínimo $\varphi = 0$, $V(\varphi = 0) = -mg\ell$ y por tanto

$$V(\varphi) = mg(-\ell \cos \varphi) = -mg\ell \cos \varphi,$$

Como vemos la aproximación funciona bastante bien. Conformes con ella calculamos la fuerza

$$\vec{F} = -\vec{\nabla}V = -\left(\frac{\partial}{\partial r}, \frac{1}{r}\frac{\partial}{\partial \varphi}, \frac{\partial}{\partial z}\right)V(\varphi)$$

Pero solo nos interesa expresar la 2.a ley de Newton para lo que pasa en $\hat{\varphi}$

$$m\ddot{\vec{r}} \cdot \hat{\varphi} = -\frac{1}{r}\frac{\partial}{\partial \varphi}V(\varphi)$$

En el lado izquierdo de la expresión de la aceleración en cilíndricas $\ddot{\vec{r}} = (\ddot{r} - r\dot{\varphi}^2)\hat{r} + (r\dot{\varphi}^2 + r\ddot{\varphi})\hat{\varphi} + \ddot{z}\hat{z}$, nos quedamos solo con la componente en $\hat{\varphi}$,

$$\ddot{\vec{r}} \cdot \hat{\varphi} = r\dot{\varphi}^2 + r\ddot{\varphi}$$

y como el hilo del péndulo es rígido e inextensible $r \equiv \ell$ solo queda de esto

$$\ddot{\vec{r}} \cdot \hat{\varphi} = \ell \ddot{\varphi}$$

En el lado derecho la derivada del potencial respecto a φ es

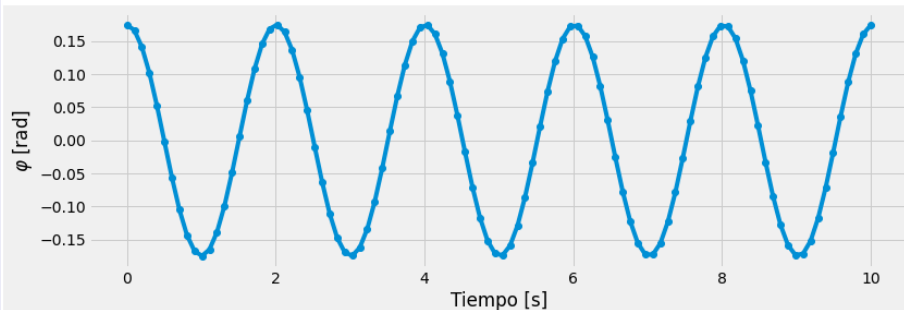
$$\frac{\partial}{\partial \varphi}V(\varphi) = mg\ell \sin(\varphi)$$

Tools — 1st class — Matplotlib: precise and reproducible graphics

- Explicit Python code for producing graphics. Students are enticed to play with it.

```
# graficación
fig, ax = plt.subplots(figsize=(12, 4))
ax.plot(tiempos, phi(tiempos), 'o-')
ax.set_xlabel('Tiempo [s]')
ax.set_ylabel(r'$\varphi$ [rad]')
```

```
Text(0, 0.5, '$\varphi$ [rad]')
```



Tools — 3rd class — SymPy: symbolic calculations

- Students effort centred on new subjects by freeing them of calculus and algebraic tasks.

```
[8]: m2_v_cuadrado = m2_v.dot(m2_v)
     m2_v_cuadrado
```

```
[8]:  $\ell^2 \sin^2(\varphi) \dot{\varphi}^2 + (\ell \cos(\varphi) \dot{\varphi} + \dot{x})^2$ 
```

Con esto la energía cinética queda

$$\begin{aligned} T(\dot{x}_1, \varphi, \dot{\varphi}) &= \frac{m_1}{2} \left(\dot{r}_1 \right)^2 + \frac{m_2}{2} \left(\dot{r}_2 \right)^2 \\ &= \frac{m_1}{2} \dot{x}^2 + \frac{m_2}{2} (\dot{x}^2 + 2\dot{x}\ell \cos \varphi \dot{\varphi} + \ell^2 \dot{\varphi}^2) \end{aligned}$$

```
[9]: # Energía cinética
     unMedio = sym.Rational(1,2) # Rational: fracción de enteros, alternatively podría haberse usado 0.5
     m1_T = unMedio*m1*m1_v_cuadrado
     m2_T = unMedio*m2*m2_v_cuadrado
     T = sym.Eq(sym.Symbol('T'), (m1_T + m2_T) ) # simplify: simplifica usando factor común y otras operaciones
     T
```

```
[9]: 
$$T = \frac{m_1 \dot{x}^2}{2} + \frac{m_2 (\ell^2 \sin^2(\varphi) \dot{\varphi}^2 + (\ell \cos(\varphi) \dot{\varphi} + \dot{x})^2)}{2}$$

```

Tools — 4th class — Equations for Lagrangian dynamics

Ecuaciones de Euler-Lagrange

Para x

```
[8]: x_EL = sym.Eq(L.rhs.diff(x) - L.rhs.diff(x.diff(t)).diff(t), 0).simplify() # ecuación igualando a cero
      x_EL
```

$$[8]: m_1 \ddot{x} + m_2 \left(-\ell \sin(\phi) \dot{\phi}^2 + \ell \cos(\phi) \ddot{\phi} + \ddot{x} \right) = 0$$

Esta es una ecuación diferencial lineal de segundo orden homogénea. De aquí podría despejarse \ddot{x}

```
[9]: sym.Eq(x.diff(t,2),
           list( sym.solve(x_EL, x.diff(t,2) ) )[0] # solveset devuelve un set, que convertimos a lista
           ) # aceleración = x punto punto [m s-2]
```

$$[9]: \ddot{x} = \frac{\ell m_2 \left(\sin(\phi) \dot{\phi}^2 - \cos(\phi) \ddot{\phi} \right)}{m_1 + m_2}$$

Pero queda en función de otra aceleración $\ddot{\phi}$.

Para ϕ

```
[10]: phi_EL = sym.Eq(L.rhs.diff(phi) - L.rhs.diff(phi.diff(t)).diff(t), 0).simplify() # ecuación igualando a cero
       phi_EL
```

Tools — 4th class — Automatisation of resolutions

- Mathematical complexity doesn't limit the scope of tackled mechanical problems.

```
[14]: sistemaEcuaciones = [  
        x_EL,  
        phi_EL,  
    ]  
variablesDespeje = [x.diff(t,2), phi.diff(t,2)] # despejar aceleraciones generalizadas  
variablesDespeje_sol = sym.nonlinsolve(sistemaEcuaciones, variablesDespeje ).args[0]
```

```
[15]: x_pp = sym.Eq(variablesDespeje[0], variablesDespeje_sol.args[0] ) # [m s-2]  
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x_pp, phi_pp
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$$[15]: \left(\ddot{x} = \frac{-\ell g m_2 \sin(\phi) + \frac{\ell m_2 (\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{m_1 + m_2 \sin^2(\phi)}}{\ell m_2 \cos(\phi)}, \ddot{\phi} = -\frac{(\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{\ell (m_1 + m_2 \sin^2(\phi))} \right)$$

Tools — 5th class — SciPy: numerical computation of results

```
[22]: # defino una función con el sistema de derivadas
      # t : no se usa en este sistema pero lo dejamos para uso posterior
      # y : lista de estado con [y[0], y[1], y[2], y[3]]
      # y[0]: x
      # y[1]: x punto
      # y[2]: phi
      # y[3]: phi punto
      # dydt : lista de derivadas
      def y_punto(t, y):
          dydt = [y[1],
                  x_pp_numpy(y[0], y[1], y[2], y[3]),
                  y[3],
                  phi_pp_numpy(y[0], y[1], y[2], y[3]),
                  ]
          return dydt

[23]: # Integración de a pasos en el tiempo
      y_ode2 = solve_ivp(y_punto, (t_rango[0], t_rango[-1]), y_inicial, t_eval = t_rango)

[25]: y_ode2.y[0]

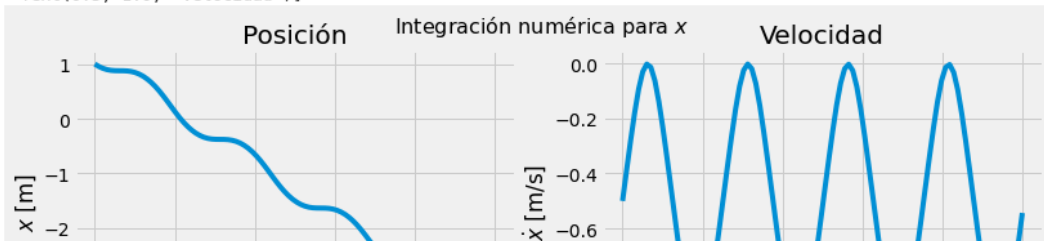
[25]: array([ 1.          ,  0.95510744,  0.92131146,  0.89820932,  0.88468059,
            0.87877042,  0.87745354,  0.87702754,  0.87352768,  0.86357726,
            0.84474673,  0.81565733,  0.77559949,  0.72423163,  0.66166451,
```

Tools — 5th class — Graphical analysis of numerical results

```
[26]: solucion = y_ode2
      nombreCoordenada = 'x'

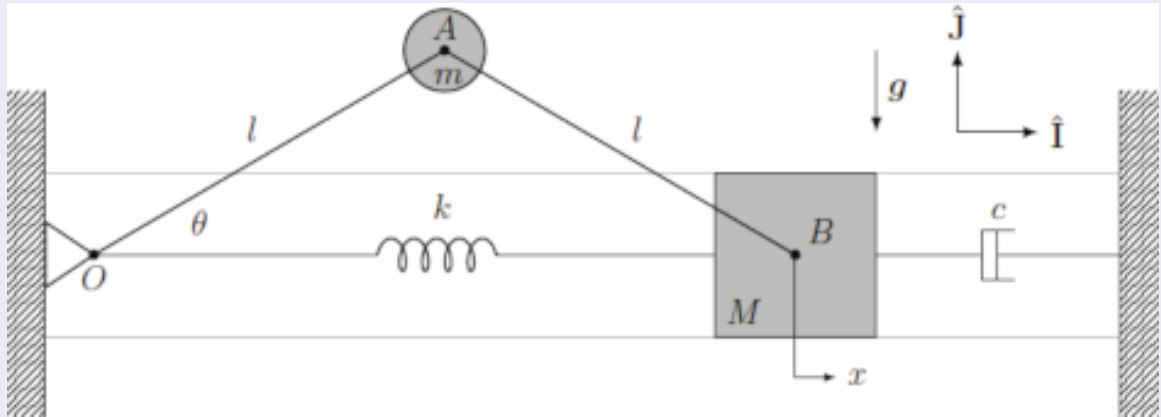
      fig, ax = plt.subplots(nrows= 1, ncols= 2, squeeze=False, figsize=(12, 4)) # dos figuras en la misma fila
      fig.suptitle('Integración numérica para $'+ nombreCoordenada + '$', fontsize=16)
      ax[0,0].plot(solucion.t, solucion.y[0]) # posición x
      ax[0,0].set(xlabel='t [s]', ylabel='$' + nombreCoordenada + '$ [m]', title='Posición')
      ax[0,1].plot(solucion.t, solucion.y[1]) # velocidad x
      ax[0,1].set(xlabel='t [s]', ylabel='$\dot{x}$ [m/s]', title='Velocidad')
```

```
[26]: [Text(0.5, 0, 't [s]'),
      Text(0, 0.5, '$\dot{x}$ [m/s]'),
      Text(0.5, 1.0, 'Velocidad')]
```



Tools — 7th class — Adding complexity

- Code from previous classes is **recycled** to model more realistic devices.



Tools — 8th class — GitHub Copilot: AI assistance for coding

- Now that the students grasp the basics they're invited to take advantage of AI
- After commenting in plain text what they need code is suggested

```
lagrangiano = (T.rhs - V.rhs).expand()
t = sym.Symbol('t') # como se deriva respecto al tiempo con la función diff se declara t como símbolo
return sym.Eq(
    lagrangiano.diff(coordenadaGeneralizada)
    - lagrangiano.diff(coordenadaGeneralizada.diff(t)).diff(t)
    , 0
).simplify()
```

[21]

```
x1_EL = eulerLagrange(T, V, x1)
x1_EL
```

[22]

$$\dots \quad \frac{\pi^2 M \ddot{x}_1}{2} - gm_1 + gm_2 + m_1 \ddot{x}_1 + m_2 \ddot{x}_1 = 0$$

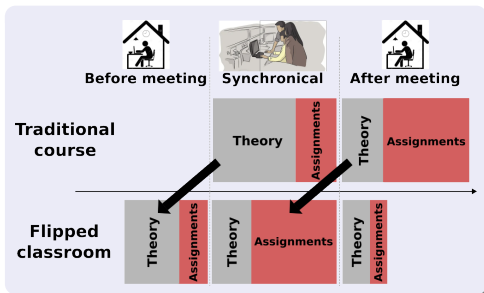
Esta es una ecuación diferencial lineal de segundo orden homogénea. De aquí se puede despejar \ddot{x}

▷ ▾

```
#Despejar x1PuntoPunto
x1PuntoPunto = sym.solve(x1_EL, x1.diff(t, t)).args[0]
```

Methodology — Weekly cycle of our flipped classroom

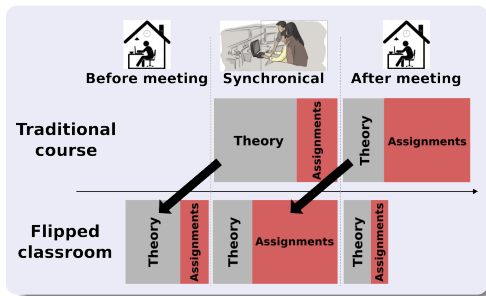
- New theory (Jupyter notebooks and videos) and assignments published on-line



	Synchronic	Theory	Assignments
Before		Read and apply	Start them
During		Consultations	Complete them
After		Additional consultations	TA's corrections

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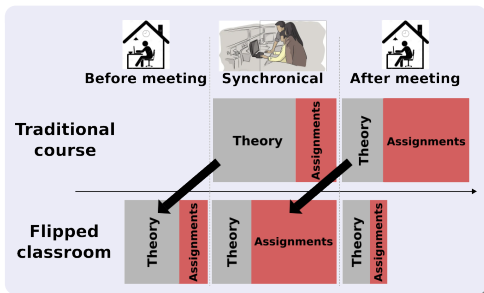
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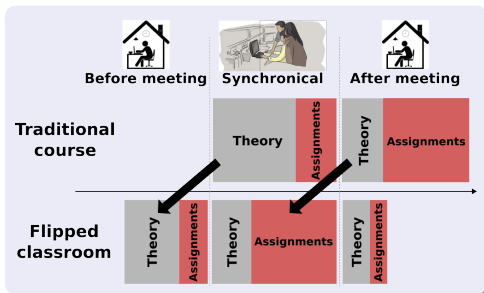
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- New theory (Jupyter notebooks and videos) and assignments published on-line
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- On-line 24/7 **asynchronous** consultations that are **public** to other students
- **synchronous** meetings with TA's to finish assignments



	Synchronic	Theory	Assignments
Before		Read and apply	Start them
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Methodology — Google Colaboratory: asynchronic remote assistance

 07 No conservativas | ej4 ☆

Archivo Editar Ver Insertar Entorno de ejecución Herramientas Ayuda [Se editó por última vez: 3 de junio](#)

+ Código + Texto

Conectar Editando

```
[ ] # Energía potencial
m1_V = - (m1* g* (- N.y)).dot(m1_r)
# pot_k1 = unMedio* ( -k1* ((l10 + x1)* (sym.cos(theta) - sym.sin(theta)) )**2 ) # mal
pot_k1 = unMedio* k1* (l10 + x1)**2 # Lo escribí yo
# pot_k2 = unMedio* -k2* (l20 + x)**2
pot_k2 = unMedio* k2* (l20 + x)**2
V = sym.Eq(sym.Symbol('V'), m1_V + pot_k1 + pot_k2 ) #agrega el potencial elastico k en la ecuacion
V
```

$$V = gm_1(-l_{10} - x_1)\sin(\theta) + \frac{k_1(l_{10} + x_1)^2}{2} + \frac{k_2(l_{20} + x)^2}{2}$$


▼ Lagrangiano

```
[ ] L = sym.Eq(sym.Symbol('\mathcal{L}'), (T.rhs - V.rhs))
L
```

$$\mathcal{L} = -gm_1(-l_{10} - x_1)\sin(\theta) - \frac{k_1(l_{10} + x_1)^2}{2} - \frac{k_2(l_{20} + x)^2}{2} + \frac{(m_0 + m_1)(2\cos(\theta)\dot{x}\dot{x}_1 + \dot{x}^2 + \dot{x}_1^2)}{2}$$

ECUACIONES DE EULER


Para x

 Victor Alexis Bettachini [Resolver](#)

31 de may. de 2021
(editado el 31 de may. de 2021)

- El estiramiento del resorte de k_1 es colineal con x_1 . No tienen sentido pensar en proyecciones (si es lo que hiciste, que realmente no entiendo).

- ¿Porque negativos los k ?

 Victor Alexis Bettachini [Resolver](#)

31 de may. de 2021

vbettachini@unlam.edu.ar

A code centred mechanics subject

2023-11-23

18 / 21

Methodology — Microsoft Teams: individualized student follow-up

A record of the weekly turn-up of assignments

Buscar

MR

Calificaciones

Vencimiento el 28 sept

Exportar a Excel

	g06e03	g06e04	g06e05	g05e01a	g05e01c	g05e02	g05e03
28 sept	28 sept	28 sept	28 sept	14 sept	14 sept	14 sept	14 sept
Buscar alumnos							
Promedio de clase							
	Visto		Visto	Devuelto	Entregado	Entregado	Entregado
				Devuelto	Entregado	Entregado	Entregado
				Entregado	Entregado	Entregado	Entregado
	Visto	Visto	Visto	Entregado	Entregado	Entregado	Entregado
				Entregado	Entregado		Entregado
	Visto	Visto	Visto	Entregado	Entregado	Visto	Entregado

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- Material: text + equations + executable code in digital notebooks in a repository

Flipped classroom

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Thank You!