



Universidad Nacional
de La Matanza



A rational mechanics course where everything is made with Python code

Bettachini, Víctor A.; Real, Mariano A.; Palazzo, Edgardo

New Media Pedagogy 23



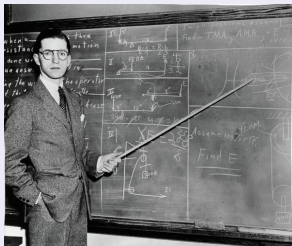
Value students and professors time

Licklider (1957): 85 % of “thinking” are actually mundane task (calculations, drawing, etc.)



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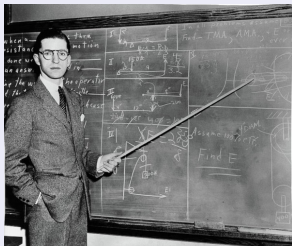
Classroom and practice: an exercise on transcription

- Professor: lessons $\xrightarrow{\text{by heart}}$ blackboard/slides



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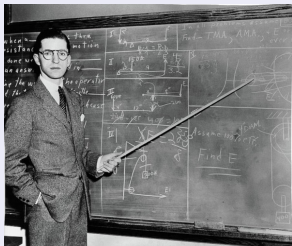
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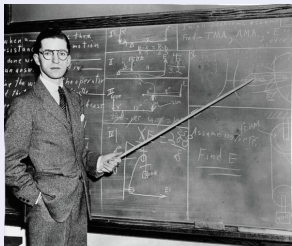
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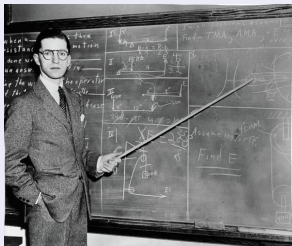
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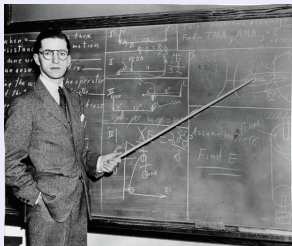
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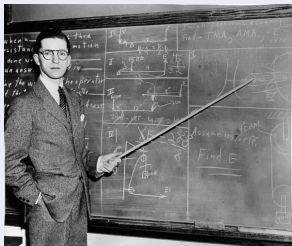
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- Professor: ideas \rightarrow new code/notes in repository

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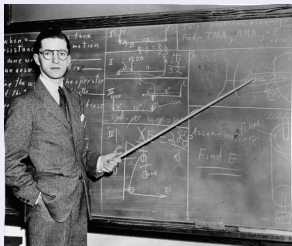
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Value students and professors time

Licklider (1957): 85 % of “thinking” are actually mundane task (calculations, drawing, etc.)



Classroom and practice: an exercise on transcription

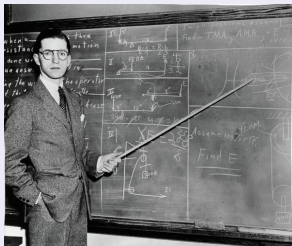
- Professor: lessons $\xrightarrow{\text{by heart}}$ blackboard/slides
- Student: blackboard/slides $\xrightarrow{\text{copies}}$ notebooks
- Práctica **reiterate** diagrames, calculations, etc.
- Boredom $\implies \downarrow$ concentration on the subject

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- Professor: ideas \rightarrow new code/notes in repository
- Student: course repository \rightarrow its own modifiable one
- Use code to solve problems = **recycle** professor's code

Value students and professors time

Licklider (1957): 85 % of “thinking” are actually mundane task (calculations, drawing, etc.)



Classroom and practice: an exercise on transcription

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100 // ...
```

- Professor: ideas \rightarrow new code/notes in repository
- Student: course repository \rightarrow its own modifiable one
- Use code to solve problems = **recycle** professor's code
- Modifying it solves different problems

The course setup: Google Colaboratory

- It runs Jupyter notebooks online, and it's free.
- Students can collaborate remotely, working on the same notebook.
- Teachers can edit and comment the work of students.

The screenshot shows a Google Colaboratory notebook titled "07 No conservativas | ej4". The interface includes a top bar with navigation options (Archivo, Editar, Ver, Insertar, Entorno de ejecución, Herramientas, Ayuda) and a status bar indicating the last edit was on June 3rd. The notebook content is divided into two main sections: "Código" and "Texto".

Código Section:

```
[ ] # 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 escribi 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
```

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

ECUACIONES DE EULER

Para x

Comments:

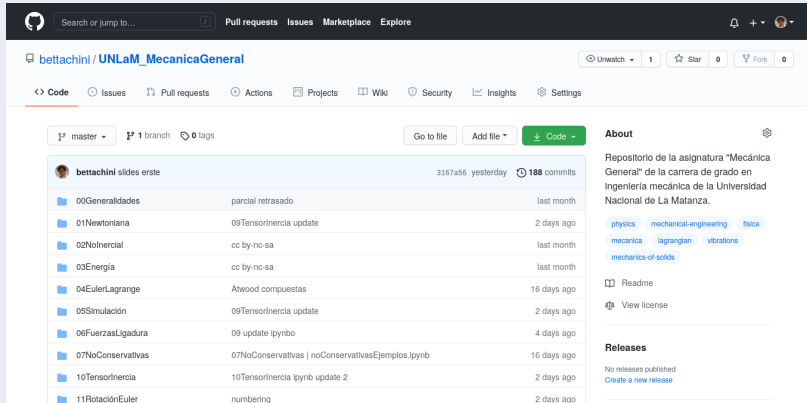
Victor Alexis Bettachini (31 de may. de 2021) (editado el 31 de may. de 2021)

- El estiramiento del resorte de k_1 es colineal con x1. No tienen sentido pensar en proyecciones (si es lo que hiciste, que realmente no entiendo).

- ¿Porque negativos los k?

The course setup: GitHub

- Course material, accesible in a clear way, and easy to keep updated.
- Google Colaboratory loads Jupyter Notebooks directly from GitHub.



bettachini / UNLaM_MecanicaGeneral

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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 ipynbo	4 days ago
07NoConservativas	07NoConservativas noConservativasEjemplos.ipynb	16 days ago
10TensorInercia	10TensorInercia ipynb 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

Class 1: Concise Mathematical Notation

- Latex typesetting, standard for 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 $\ddot{\vec{r}} = (\ddot{r} - r\dot{\varphi}^2)\hat{r} + (r\ddot{\varphi} + \dot{r}\dot{\varphi})\hat{\varphi} + \ddot{z}\hat{z}$, nos quedamos solo con la componente en $\hat{\varphi}$,

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

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

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

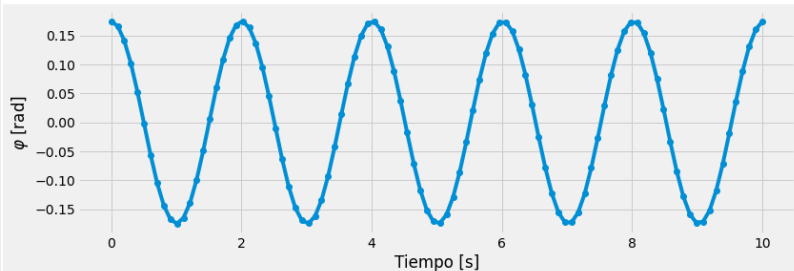
Course Overview

Class 1: precise and reproducible graphics

- The use of Python code for producing graphics is explicit, making the students 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]')



Course Overview

Class 3: symbolic calculations

- These students have completed courses in Calculus and Algebra, now it's time to focus on applying the tools acquired in those courses.

```
[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

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

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

```



Class 4: 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]: m1*x + m2*(-l*sin(phi)*phi**2 + l*cos(phi)*phi**2) = 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]: l*m2*(sin(phi)*phi**2 - cos(phi)*phi**2)  
x = -----  
      m1 + m2
```

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
```



Class 4: Automation of resolutions

- No heavy calculations consuming the energy of the students.
- Their complexity does not limit the mechanical problems that can be tackled.

```
[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
```

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



Class 5: Numerical analysis

- Explicit solutions.

```
[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,
            0.588266   ,  0.50468237,  0.41250381,  0.31433661,  0.21366454,
            0.11444308,  0.02023394, -0.06599563, -0.14244216, -0.20809592,
            -0.26250272, -0.30576388, -0.33796804, -0.35953138, -0.37175469,
            -0.3760772  , -0.3701011  , -0.37051150, -0.36907406, -0.36807076])
```

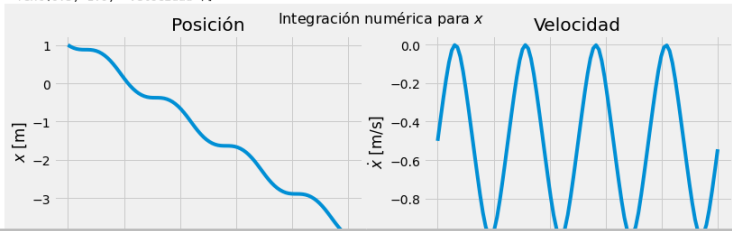
Course Overview

Class 5: analysis of 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')]
```



0 s 1 Python 3 (ipykernel) | Idle

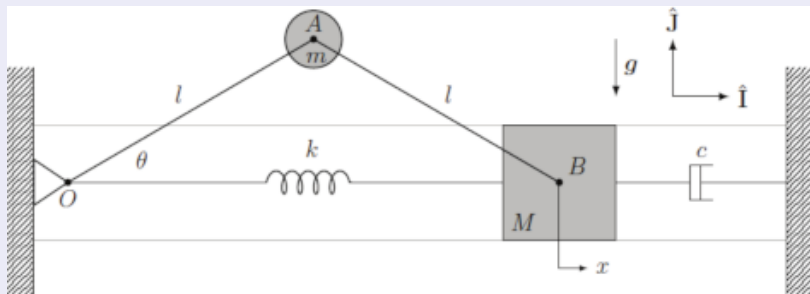
Saving completed

Mode:

Course Overview

Class 7: Adding complexity

- Reuse code from previous classes to study complex situations.
- Similar to real world problems.



Engineering students must take advantage of code at every single lecture



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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]:
```

$$\ddot{x} = \frac{-\ell g m_2 \sin(\phi) + \frac{\ell m_2 (\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{m_1 + m_2 \sin^2(\phi)}}{\ell m_2 \cos(\phi)}, \quad \ddot{\phi} = -\frac{(\ell m_2 \cos(\phi) \dot{\phi}^2 + g m_1 + g m_2) \sin(\phi)}{\ell (m_1 + m_2 \sin^2(\phi))}$$



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```
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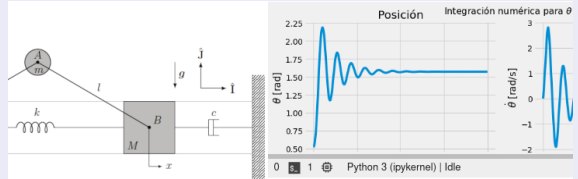


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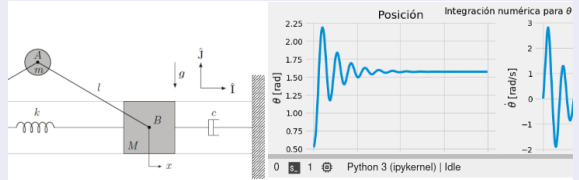


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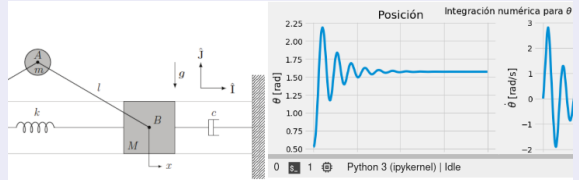


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```



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

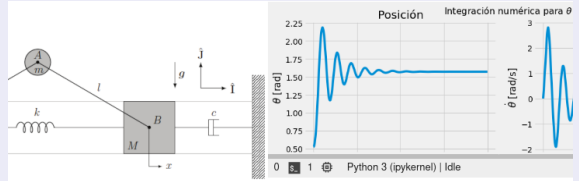
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```



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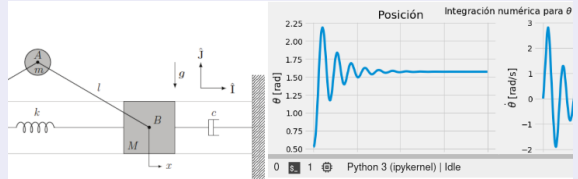
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```



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

All course material can be edited on-line



All course material can be edited on-line

On-line programmable notebook: text + equations + code

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PÉNDULO ENHEBRADO SOLVED.IPYNB

Launcher cursoJupyter.ipynb pénduloEnhebradoSolved.ipynb Python 3

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
```

```
[14]: 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()
```

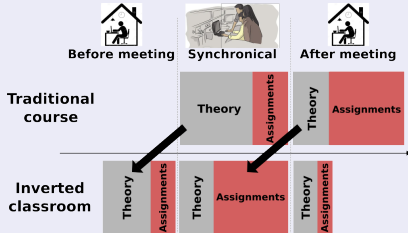
```
[16]: m (2a cos(theta_1 - theta_2) \ddot{\theta}_1^2 + g cos(2\theta_1 - \theta_2) + g cos(\theta_2) + 2d \ddot{\theta}_2^2 - 2\ddot{d})
```


Synchronical and asynchronical work on the code

New theory alongisde its worked examples in programmable notebooks

- On-line 24/7 **asynchronical** consultations that are **public** for others to see

Flipped classroom



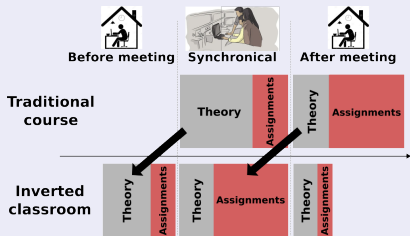
Synchronic	Theory	Assignments
Before	Read and apply	Start them
During	Consultations	Complete them
After	Additional consultations	TA's corrections

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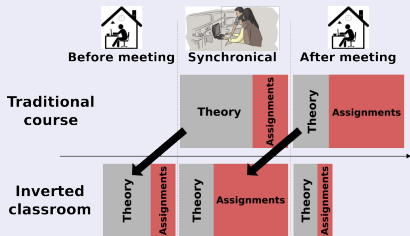
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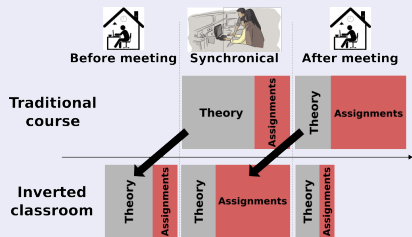
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- On a weekly basis these **must** be turned-in for scoring


Flipped classroom



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Asynchronous corrections and remote assistance

Student's work can be commented and edited in Google Colaboratory

 07 No conservativas | ej4 ☆

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

Comentar Compartir Configuración Perfil

+ 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
```

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

ECUACIONES DE EULER

 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 x1. No tienen sentido pensar en proyecciones (si es lo que hiciste, que realmente no entiendo).
- ¿Porque negativos los k?

The exam is just another exercise.

- The students send their notebook.
- Feedback is inserted in between the student's work.

```
[ ]: sym.Eq(flig_rho_rep, flig_rho)
```

[119]: $Q_\rho(\lambda) = \lambda$

Esta fuerza efectivamente es igual a λ , pero ¿por qué? No das una justificación.

Entonces la fuerza de ligadura Q_ρ , o lo que es lo mismo, la fuerza que hace la barra rígida esta dada por la ecuación:

```
[ ]: f_lig_rho = sym.Eq(sym.Function('Q_rho')(theta1, theta1.diff(t), theta2, theta2.diff(t)) , lambda_final)
f_lig_rho
```

[120]: $Q_\rho(\theta_1, \dot{\theta}_1, \theta_2, \dot{\theta}_2) = -m \left(\ell \dot{\theta}_2^2 + a \sin(\theta_1 - \theta_2) \ddot{\theta}_1 + a \cos(\theta_1 - \theta_2) \dot{\theta}_1^2 + g \cos(\theta_2) \right)$

No es la expresión buscada.

Entre las variables hay una que no está marcada en la izquierda de la igualdad, donde decís que la expresas en función de los θ_i y $\dot{\theta}_i$.

Podés ver que te quedó expresado en función de $\ddot{\theta}_1$. Esta puede obtenerse de resolver el sistema con las otras dos ecuaciones de Euler-Lagrange.

Individualized student follow-up at Microsoft Teams

A record of the weekly turn-up of assignments

Calificaciones													
Vencimiento el 28 sept													
g06e03		g06e04		g06e05		g05e01a		g05e01c		g05e02		g05e03	
28 sept		28 sept		28 sept		14 sept		14 sept		14 sept		14 sept	
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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A course centred on code

- Theory: text + equations + executable code in digital notebooks.

Inverted classroom



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Current developments



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2023 Students feedback improved:



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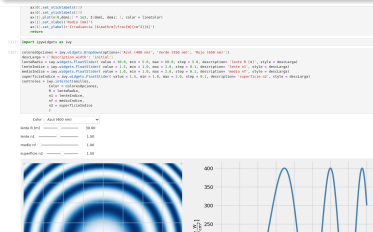
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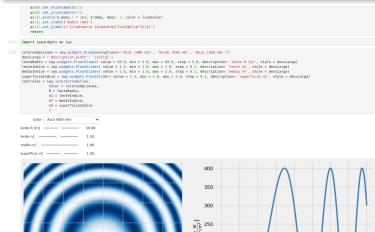
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Evaluating each one of them → higher student's performance

2024

- A course on optics and waves will incorporate part of the methodology
- AI assistance in code generation employing *GitHub Copilot*



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

[121]

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

[122]

$$\frac{m^2 M \ddot{x}_1}{2} - g m_1 + g m_2 + m_1 \ddot{x}_1 + m_2 \ddot{x}_1 = 0$$

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

[123]

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