

Teaching of Apparent Mass Increase for Understanding News Media on the Higgs Boson and Crystallized Intelligence Assessment for Community College Physics Students

Tak Cheung

CUNY Queensborough Community College, Bayside, USA

•Received 19 September 2013 •Revised 11 February 2013 •Accepted 21 April 2014

News Media has been an obvious convenient information source for college students due to their digital experience. The recent discovery of the Higgs boson and the confirmation of the Brout-Englert-Higgs mechanism as reported in the News Media had created confusion among our community college students as they are familiar with the concept of the negative contribution of the binding energy to the mass term taught in physics as well as in chemistry classes. Related questions such as “Would a body mass come mainly from the BEH mechanism?” would become difficult to answer without some numerical illustrations at the community college level. Given this student learning challenge, examples such as a force pulling on a composite 2-block system with internal motion and a truck as a driven oscillator on a washboard road have been formulated to supplement the News Media information. The explanation of apparent mass increase for zero initial mass (via dispersion relation) and the spontaneous symmetry breaking that would support small oscillation (bosons) at the lowest energy state with non-zero field value are also included for students interested in studying physics in a community college. Physics education research assessment in terms of fluid intelligence development, crystallized intelligence practice, and one-shot versus incremental learning are discussed.

Keywords: internal motion, dispersion relation, spontaneous symmetry breaking, Higgs boson, fluid intelligence, crystallized intelligence, one-shot learning

Correspondence: Tak Cheung

CUNY Queensborough Community College, 222-05 56th Ave, Bayside, NY 11364, USA

E-mail: tcheung@qcc.cuny.edu

doi: 10.12973/ejpc.2015.00003a

Copyright © 2015 by the authors; licensee iSER, Ankara, TURKEY. This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0)

(<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original paper is accurately cited.

INTRODUCTION

The News Media has been an obvious convenient information source for college students due to their digital experience. CERN had made their data available for public download as well. The recent confirmation of the Higgs boson and the Brout-Englert-Higgs BEH mechanism as reported in the News Media had created confusion among our community college students who are familiar with the concept of the negative contribution of the binding energy to the mass term taught in physics as well as in chemistry classes. For example, the helium nucleus has less energy than the energies of the separate nucleons added together. When the nucleons were combined together in the nucleus the mass of the helium nucleus was $0.030377 u$ less than expectation. The disappearing mass would represent the negative binding energy (PhysicsNet 2015). Related questions such as “Would a body mass come mainly from the BEH mechanism?” become difficult to answer without any numerical illustration at the community college level. In fact, the Youtube webpage (Leinweber 2013) has explanation videos such as “Your Mass is NOT From the Higgs Boson”, but such video information could not serve well as a learning platform for community college students.

Given this student learning challenge, examples such as a force pulling on a composite object with internal motion and a truck as a driven oscillator on a washboard road have been formulated. The apparent mass increase for zero initial mass and its relationship to spontaneous symmetry breaking in the Higgs boson understanding at the community college level are discussed. Such formulations will encourage students to broaden their horizon, which is important with the science of learning study results that leaning motivation is rooted in the genes (Kovas et al 2015). The flight of top performance STEM students away from STEM careers could be mediated as well (Chen 2015). In terms of physics education research assessment, physics has been found to provide an important opportunity for student to practice their fluid intelligence (Rifkin and Georgakakos 1996). The physics ill-posed questions are good examples for students to develop fluid intelligence. The logical deviation steps in introductory physics to illustrate these advanced concepts would be a review for students to sharpen their crystallized intelligence in terms of following and understanding the mathematical steps in physics. Incremental learning where new knowledge is acquired gradually through trial and error in working out physics numerical examples would be different from one-shot learning, where the mind learns rapidly from a single stimulus and its consequence in a standalone example of an object sliding along a rotating hoop example. The paper aims to show (1) the apparent mass increase in classical mechanics, (2) the Higgs field analogy using a standard Washboard Road interaction with a car, and (3) massless particle getting a mass value via dispersion relation and the spontaneous symmetry breaking that would support small oscillation (bosons) at the lowest energy state with non-zero field value.

APPARENT MASS CHANGE IN MECHANICS

Concerning Two examples are offered to illustrate the concept of apparent mass change in mechanics using Newton's Laws at the algebra physics level. The inclusion of numerical information has been found to be useful for students to keep track of the reasoning steps in terms of the energy budget.

Basically when an internal motion would “shake-off” a mass component in its response to an external force, the apparent mass would decrease as illustrated in Example I. On the other hand, when an internal motion would “drag-along” another mass into its response to an external force, the apparent mass would increase as

illustrated in Example II. Two video demonstrations contrasting a pendulum swinging inside a moving bucket versus a pendulum sitting on a moving bucket are included as supplemental illustration. The bucket and pendulum would sit on a car and the system would receive energy from a compressed spring and would move along a track. The friction in the wheel axle would stop the system. In the case where partial energy was diverted to the swinging pendulum, the plastic bucket would travel a lesser distance. In other words, the case where the non-swinging pendulum sat on the bucket would ride further along the track. Applying Newton's Second Law in the non-inertia frame would require a g_{eff} such that the oscillation frequency $\omega = \sqrt{g_{\text{eff}}/L}$ (with L being the length of the pendulum). Note that $g_{\text{eff}} = \sqrt{(\text{gravity}^2 + \text{acceleration}^2)}$, consistent with the Principle of Equivalence discovered by Einstein.

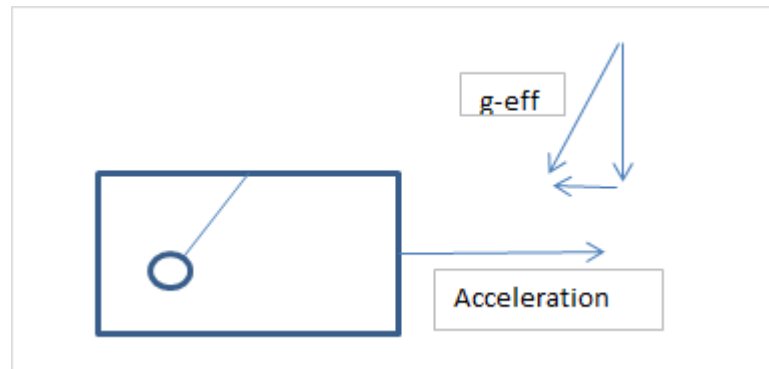


Figure 1. A pendulum inside an accelerating car

Example I

Case A

A system consisted of two blocks. A 100kg block was in contact with a table given a coefficient of kinetic friction of 0.1. A 50kg block was on top of the 100kg block. A 400N external force was applied to the 100kg block. What would be coefficient of static friction along the block interface for the two blocks to move together?

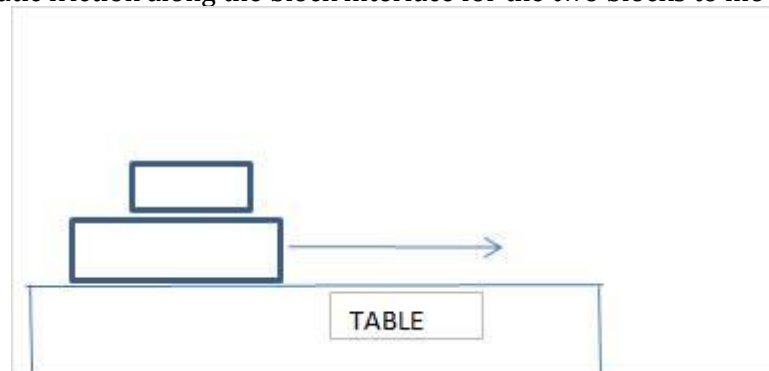


Figure 2. Pulling on the larger block example via an external force.

Applying Newton's Second Law $F = ma$ and friction $= \mu m(9.8)$ to the entire system

$$\text{We have } 400 - (0.1)(100 + 50)(9.8) = (100 + 50) a$$

The acceleration $a = 1.686 \text{ m/s/s}$

Applying Newton's Second Law $F = ma$ and friction $= \mu m (9.8)$ to the 50kg block

$$\text{We have } \mu(50)(9.8) = 50 (1.686)$$

The coefficient of static friction $= 0.17$, a minimum required value for the 50kg to be at rest relative to the 100kg block

After moving the system for a distance of 10 meter, we have the following analysis for the motion of the two blocks driven by the external energy of 4000 J (assuming the block interface has coefficient of static friction larger than 0.17 such that two blocks moved together with same speed).

The elapsed time would be $\sqrt{[2(10)/1.686]} = 3.4442$ sec such that $v^2 = a^2t^2 = (1.686)^2 [2(10)/1.686]$

The KE = $(1/2) m v^2 = (1/2)(100+ 50)(1.686)^2 [2(10)/1.686] = 2,530$ J

table friction work done = $(0.1) (100 + 50)(9.8)(10) = 1,470$ J

The energy budget would be $4000 \text{ J} = 2530\text{J} + 1,470\text{J}$, the external force work done = kinetic energy of the system + heat (the table friction work done)

Case B

Reconsider the above problem when the block interface coefficient of static friction is less than 0.17 such that the 50kg block would move relative to the 100kg block. Let the block interface coefficient of kinetic friction be 0.15.

Applying Newton's Second Law $F = ma$ and friction = $\mu m (9.8)$ to the 100kg block
We then have $400 - 0.1(100+50) (9.8) - 0.15(50) (9.8) = 100 a$

The 100 kg acceleration $a = 1.795$ m/s/s

After moving the system for a distance of 10 meter, we have the following analysis for the motion of the two blocks driven by the external energy of 4000 J

The elapsed time would be $\sqrt{[2(10)/1.795]} = 3.1823$ sec

Then $v^2 = a^2t^2 = (1.795)^2 [2(10)/1.795]$

The 100kg kinetic energy $(1/2) m v^2 = (1/2) (100)(1.795)^2 [2(10)/1.795] = 1,795$ J

Heat generated by the table friction would still be 1,500 J, same as before.

Applying Newton's Second Law $F = ma$ and friction = $\mu m (9.8)$ to the 50kg block

We then have $0.15(50) (9.8) = 50 a$

The 50kg block acceleration = 1.47 m/s/s

The 50 kg kinetic energy = $(1/2) (50) (1.47)^2 [(2(10)/1.795)] = 601.9$ J, since the elapsed time would be identical for both blocks

The block interface friction work done as heat would be determined by the relative distance moved along the two blocks.

The relative distance = $(1/2) (\text{relative acceleration}) (\text{elapsed time})^2$

The relative distance = $(1/2) (1.795 - 1.47) [2(10)/1.795] = 1.811$ meters

The block interface friction work done as heat = $(0.15) (50) (9.8) (1.811) = 133.1$ J

After moving a distance of 10 m, the energy budget would be $4000 \text{ J} = 1,470\text{J}$ (table heat) + 1795J (the 100kg KE) + 601.9 J (the 50kg KE) + 133.1 J (heat between block interface)

When the 400N external force was applied through a pulley that was connected to a hanging mass M, the PE loss $M(9.8)(\text{height})$ must be equal to KE of the hanging mass, 50kg block and 100kg block; and the table heat loss and block interface heat loss. The release of the hanging mass (the let-go action) to start the motion could be interpreted as a collision phenomenon where two equal and opposite direction internal forces were created along the connecting string. The string would support two tensions, namely, one tension pulling the 100kg and 50 kg blocks into motion and the other tension preventing the hanging mass from executing a free falling motion.

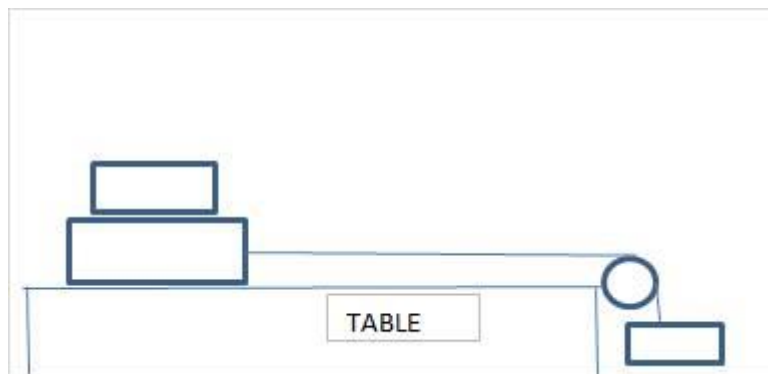


Figure 3. Pulling on the larger block example via a pulley mechanism

Case-A hanging mass would obey the Newton's Second Law equation, $M(9.8) - 400 = M(1.686)$, such that Case-A hanging mass would be 49.30 kg. Case-B hanging mass would obey the Newton's Second Law equation, $M(9.8) - 400 = M(1.795)$, such that Case-B hanging mass would be 49.97 kg.

In order for the hanging mass to fall 10 meter in distance, Case-A would take 3.4442 sec for a hanging mass of 49.30 kg and Case-B with internal motion would take 3.1823 sec for a hanging mass of 49.97 kg.

Let us modify Case-B such that the hanging mass would become 49.30 kg and call this Case B'.

Case-B' Analysis

Newton's Law for the hanging mass: $49.30(9.8) - \text{Tension} = 49.30 a$

Newton's Law for the 100 kg block: $\text{Tension} - 0.1(100 + 50)(9.8) - 0.15(50)(9.8) = 100a$

Solving the equation would give acceleration of 1.75914 m/s/s and Tension of 396.4 N

In terms of duration, Case-A would have an acceleration of 1.686 m/s/s and would take 3.4442 sec to move 10 meter distance. Case-B' would have an acceleration of 1.759 m/s/s and would take 3.3718 sec to move 10 meter distance. Therefore, the hanging mass of 49.30 kg would be connected to a "lighter object" with a tension of 396.4 N in Case-B' when compared to Case-A with a tension of 400N.

Example II

Case-A

A 100kg block was in contact with a table with coefficient of kinetic friction of 0.1. A 50kg block was on top of the 100kg block. A 400N external force was applied to the 50kg block. What would be coefficient of static friction along the block interface for the 50kg block to move only?

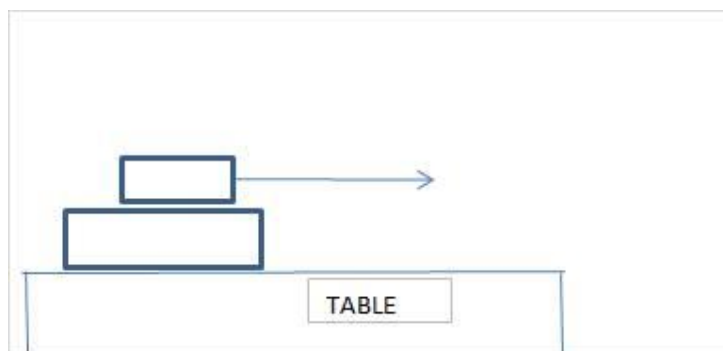


Figure 4. Pulling on the smaller block example via an external force.

Applying Newton's Second Law $F = ma$ and friction $= \mu m(9.8)$ to the 50kg block
 We then have $\mu(50)(9.8) = 0.1(100 + 50)(9.8)$

The coefficient of static friction = 0.13, a value not to be exceeded for the 100kg to be at rest relative to the moving 50kg block.

After moving the 50kg block for a distance of 10 meter, we have the following analysis for the motion of the 50kg block driven by the external energy of 4000 J (assuming that only the 50kg would move given the block interface coefficient of static friction = 0.12

Applying Newton's Second Law $F = ma$ and friction $= \mu m(9.8)$ to the 50kg block

We have $400 - 0.12(50)(9.8) = 50 a$

The 50kg acceleration = 6.824 m/s/s

The elapsed time would be $\sqrt{[2(10)/6.824]} = 1.712$ sec such that $v^2 = a^2t^2 = (6.824)^2 [2(10)/6.824]$

The KE = $(1/2)m v^2 = (1/2)(50)(6.824)^2 [2(10)/6.824] = 3,412$ J

Block interface friction work done = $(0.12)(50)(9.8)(10) = 588$ J

The energy budget would be $4000 \text{ J} = 3,412 \text{ J} + 588 \text{ J}$, the external force work done = kinetic energy of the 50kg block + heat (the block interface friction work done)

Case-B

Reconsider the above problem when the block interface coefficient of static friction is more than 0.13 such that the 50kg block motion would drag the 100kg block along. Let the block interface coefficient of kinetic friction be 0.4.

After moving the system for a distance of 10 meter, we have the following analysis for the motion of the two blocks driven by the external energy of 4000 J.

Applying Newton's Second Law $F = ma$ and friction $= \mu m(9.8)$ to the 50kg block

We have $400 - 0.4(50)(9.8) = 50 a$

The 50kg acceleration = 4.08 m/s/s

Applying Newton's Second Law $F = ma$ and friction $= \mu m(9.8)$ to the 100kg block

We have $(0.4)(50)(9.8) - 0.1(100 + 50)(9.8) = 100a$

The 100kg acceleration = 0.49 m/s/s

Note that the acceleration of the 50 kg relative to its 100kg support would be $(4.08 - 0.49) = 3.59$ m/s/s

After the 50kg block moved for a distance of 10 meter, we have the following analysis for the motions driven by the 4,000J external energy.

The elapsed time would be $\sqrt{[2(10)/(4.08)]} = 2.214037$ sec

And that $v^2 = a^2t^2 = (4.08)^2 [2(10)/4.08] = 81.6$ m²/s²

The 50kg KE = $(1/2)(50)(81.6) = 2,040$ J

The 100kg KE = $(1/2)(100)(0.49)^2(\text{elapsed time})^2 = (1/2)(100)(0.49)^2 [(2(10)/4.08)] = 58.85$ J

Table distance travelled by 100kg block = $(1/2)(0.49)(\text{elapsed time})^2 = (1/2)(0.49)[(2)(10)/4.08] = 1.20098$ m

Heat between table interface = $0.1(100 + 50)(9.8)(1.20098) = 176.54$ J

Block interface heat generated by friction = $0.4(50)(9.8)(10 - 1.20098) = 1724.61$ J

The energy budget would be $4000 \text{ J} = 2,040 \text{ J}$ (50kg KE) + 58.85 J (100 kg KE) + $1,724.61 \text{ J}$ (block interface heat) + 176.54 J (Table heat)

Consider that the 400N external force was applied through a pulley that was connected to a hanging mass M.

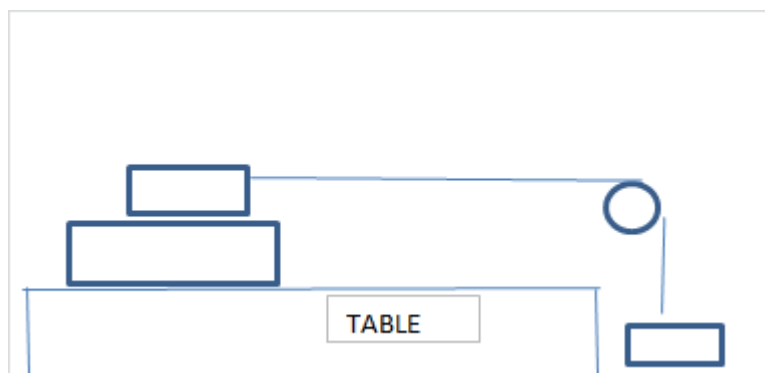


Figure 5. Pulling on the smaller block example via a pulley mechanism

Case-A hanging mass would obey the Newton's Second Law equation, $M(9.8) - 400 = M(6.824)$, such that Case-A hanging mass would be 134.4 kg. Case-B hanging mass would obey the Newton's Second Law equation, $M(9.8) - 400 = M(4.08)$, such that Case-B hanging mass would be 69.93 kg.

In order for the hanging mass to fall 10 meter in distance, Case-A would take 1.712 sec and Case-B with internal motion would take 2.214 sec. Let us modify Case-B such that the hanging mass would become 134.4 kg and call this Case B'.

Case-B' Analysis

Newton's Law for the hanging mass: $134.4(9.8) - \text{Tension} = 134.4 a$

Newton's Law for the 50 kg block: $\text{Tension} - 0.4(50)(9.8) = 50a$

Solving the equation would give acceleration of 6.0798 m/s/s and Tension of 500N.

In terms of duration, Case-A would have an acceleration of 6.824 m/s/s and would take 1.712 sec to move 10 meters distance. Case-B' would have an acceleration of 6.0798 m/s/s and would take 1.8137 sec to move 10 meters distance. Therefore, the hanging mass of 134.4 kg would be connected to a "heavier object" with a tension of 500 N in Case-B' when compared to Case-A with a tension of 400N.

Washboard Road Driving Resonance

In order to illustrate the Higgs mechanism as a resonance with a background Higgs field, the following Washboard Road example in a standard physics textbook was found to be illustrative.

"A person driving a truck on a washboard road, one with regularly spaced bumps, notices an interesting effect: When the truck travels at low speed, the amplitude of the vertical motion of the car is small. If the truck's speed is increased, the amplitude of the vertical motion also increased, until it becomes quite unpleasant. But if the speed is increased yet further, the amplitude decreases, and at high speed the amplitude of the vertical motion is small again. Explain what is happening." College Physics Knight, Jones and Field, 2nd edition, Pearson 2013 Ch14 Q20.

A conceptual analysis using energy conservation would give KE before entering the Washboard Road = KE in the Washboard Road + PE car spring such that the car would slow down. The above question could be further analyzed using the following standard methodology in introductory calculus physics for community college students in the pre- engineering curriculum. Standard book examples include (1) Physics for Scientists and Engineers Serway & Jewett, Seventh Edition 2008 Section 15.7, (2) Fundamentals of Physics Halliday Resnick Walker Ninth Edition 2011 Section 15.9 with amplitude given in Ch15 Problem 61.

For a driven oscillator in the x-direction with mass m and spring constant k
Equation becomes $m \cdot d(dx/dt)dt + kx = F_0 \cdot \sin(\omega t)$, driven oscillation no damping

Solution $x = x_{max} \cdot \cos t (\omega t + \phi)$ with $x_{max} = F_0/m / (\omega^2 - \omega_0^2)$

A car riding on a Washboard road can be modeled as a point mass with a vertical spring that can oscillate vertically to absorb the shocks. For a Washboard road, the road height y_r can be written as $R \cdot \sin (2 \cdot \pi \cdot x / \lambda)$. When height as a function of time is written as $y(t)$, then $y(0)$ be the spring equilibrium neutral height such that $y(0) = L - mg/k$. The oscillation would depend on $y(t) - y(0)$. The vertical spring (k spring constant, natural length L) would have a change of length relative to the height of the road, y_r such that the $y(t) - y_r$ should be used in the equation.

Equation of motion would become $m \cdot d(dy/dt)dt = -k(y - y_r - L) - mg$

Equation would become $m \cdot d(dy/dt)dt = -ky + ky_r + kL - mg$

Equation would become $m \cdot d(dy/dt)dt = -ky + ky_r + k(L - mg/k)$

Equation would become $m \cdot d(dy/dt)dt = -ky + ky_r + ky(0)$

Equation would become $m \cdot d(dy/dt)dt = -k(y - y(0)) + ky_r$

We can measure y relative to $y(0)$, and call that y again

Equation would become $m \cdot d(dy/dt) = -ky + ky_r$

Equation would become $m \cdot d(dy/dt) + ky = ky_r = kR \cdot \sin(2 \cdot \pi \cdot x / \lambda)$

The standard solution of a driven oscillator as discussed above can be used directly with $F_0 = kR$ and $\omega = 2 \cdot \pi \cdot \xi / \lambda$

Vertical max amplitude = $kR/m / ((\omega^2 - \omega_0^2))$

Stored oscillation energy PE-osc = $k \cdot (\text{vertical max amplitude})^2 / 2$

PE-osc would become $k \cdot k \cdot R^2 / 2 / m / m / ((\omega^2 - \omega_0^2)) / ((\omega^2 - \omega_0^2))$

Knowing $\omega_0^2 = k/m$

Then PE-osc could be rewritten as $kR^2 \cdot \omega_0^4 / 2 / ((\omega^2 - \omega_0^2)) / ((\omega^2 - \omega_0^2))$

This stored energy must come from the car such that the car would slow down upon entering the Washboard Road section

Energy conservation would require $(1/2) m (v\text{-before})^2 = (1/2) m (v\text{-washboard})^2 + \text{PE-osc}$ such that the $v\text{-washboard} < v\text{-before}$, the velocity before entering the Washboard Road

If we do not know there is a Washboard Road, then the apparent mass, m-app, (could be called effective mass) of the car must have increased

Equation becomes $(1/2) m (v\text{-before})^2 = (1/2) (m\text{-app}) (v\text{-washboard})^2$

Therefore $m\text{-app} = m + (2 \cdot \text{PE-osc} / v\text{-washboard}^2) = m + (2 \cdot \text{PE-osc} / (mv^2 - 2 \cdot \text{PE-osc}))$

The apparent mass increase, $2 \cdot \text{PE-osc} / v\text{-washboard}^2$, would be the result of the interaction with the Washboard Road, if one does not know that there is a Washboard Road. The interaction PE-osc would include the contribution of the Washboard Road Amplitude R and the $\omega = 2 \cdot \pi \cdot x / \lambda$

The apparent mass increase could also be written as $2 \cdot \text{PE-osc} / (mv^2 - 2 \cdot \text{PE-osc})$ in terms of the velocity before the onset of interaction with the Washboard Road, which is a background field, so to speak. Basically when a speed value reduces, there could be an interpretation of apparent mass increase.

The quantum physics statement that the Higgs background field gives rise to otherwise massless elementary particle would be more realistic to community college students with the swinging pendulum and the Washboard Road analogies. Note that the proton has three quarks but the majority of the proton mass value contribution would come from the interaction energy between the three quarks. In this case the gluon interaction energy is not coming from the interaction with the Higgs field. The gluon interaction energy would be similar to the internal motion energy if one demands a classical mechanics illustration.

Apparent mass increase with zero initial mass via dispersion relation

The interaction with a background field would slow down an object in classical mechanics and give rise to additional mass, but how about the case that the initial mass is zero? When would a massless object be a particle? Light slows down inside refractive material, would the light gain mass? EM waves slow down inside waveguide; would the EM wave gain apparent mass? In order to answer these questions, a follow up class in modern physics in the fourth semester on matter wave in a community college would be needed. We can use modern physics to show that a mass term can be contained in the dispersion relation. First we recall first year calculus physics discussion on dispersion phenomena with the students.

Dispersion relation describes the relationship between wavelength- λ and frequency- f (wave vector k and angular frequency ω) inside a medium.

Recall string vibration

A typical vibrating string could carry a wave in the x -direction. The displacement in the y -direction could be written as

$$T \frac{\partial^2 (y/\partial x)}{\partial x^2} = \rho \frac{\partial^2 (y/\partial t)}{\partial t^2} \quad \text{with } v = \sqrt{T/\rho} = \text{wavelength-}\lambda \cdot \text{frequency-}f$$

We have $\lambda \cdot \omega = 2\pi \sqrt{T/\rho}$ or $\omega^2 = k^2 (T/\rho)$, k is the usual wave vector $2\pi/\lambda$, $\omega = 2\pi f$

Making a small extension on the spring could be described by an equation.

A real string such as guitar application would require stiffness to be included

$T \frac{\partial^2 (y/\partial x)}{\partial x^2} - Q S^2 (\text{gyration radius})^2 \frac{\partial^4 y}{\partial x^4} = \rho \frac{\partial^2 y}{\partial t^2}$ with Q modulus of elasticity, S cross section area

The dispersion relation would become $T k^2 + 4\pi^2 Q S (\text{radius})^2 k^4 = \rho S \omega^2$ when $y = \text{constant} \cdot \exp(2\pi i(kx - \omega t))$, following the derivation found in Morse: Vibration p167.

http://www.physics.udel.edu/~jim/PHYS460_660_11S/Motion%20of%20a%20string/Motion%20of%20a%20realistic%20string.htm

The point for the students to recognize is that a dispersion relation between wavelength and frequency (wave vector and angular frequency) is derivable from a vibrating string wave equation. In fact, $d\omega/dk$ taught as group velocity is a regular topic in first year calculus physics.

The matter wave concept was proposed by de Broglie in his dissertation (de Broglie 1925a). A typical community college modern physics class would cover the special relativity, matter wave concept, mass energy conversion, and uncertainty principle. The de Broglie $\lambda = h/\text{momentum}$ concept insertion into the equation $E^2 = (pc)^2 + (mc^2)^2$ from relativistic mechanics would give $\omega^2 = k^2 c^2 + m^2 c^4 / \hbar^2 = k^2 c^2 + c^2 / \text{Compton wavelength}$, such that the equation is called the dispersion relation given the Compton wavelength = \hbar/mc ($\hbar = h/2\pi$ with h as the Planck's constant). The important point is that the dispersion relation can contain a mass term.

Light propagation in a refractive medium formulated by Maxwell $\Delta \Psi = (1/c^2) \partial(\partial \Psi / \partial t) / \partial t$ with the Laplace operator $\Delta (\Delta \Psi = \sum \partial^2 \Psi / \partial x_i^2, \text{ sum of second partial derivatives in the Cartesian coordinates } x_1, x_2, x_3)$. The corresponding dispersion relation would be $\omega^2 = k^2 c^2$ for a 3-dim scalar field in vacuum such that $\Psi(\mathbf{x}, \tau) = \Psi_0 \exp(i\mathbf{k} \cdot \mathbf{x} - \omega t)$ with wave vector \mathbf{k} could satisfy the wave equation. De Broglie considered the light propagation expression in refractive medium (De Broglie 1925b). De Broglie expressed the refractive index n as $\sqrt{1 + \omega_0^2/\omega^2}$ and showed that the wave equation (using de Broglie notation) would become $\Delta \Psi = (n^2/c^2) \partial(\partial \Psi / \partial t) / \partial t$ with the dispersion relation $\omega^2 = k^2 c^2 - \omega_0^2$ with the bonus that the minus sign would be consistent with the interpretation of virtual photons with negative mass-squared in a refractive medium.

For light travels inside refractive medium, the dispersion relation would give negative mass-squared, which is not a good analogy for the Higgs boson. Note that EM waves slow down inside waveguide, so it would appear to gain mass. But a wave guide is not a vacuum state so it is not a good analogy for the Higgs boson. The classical electromagnetic example whose virtual photons have positive mass is propagation in a rectangular waveguide. The TE₁₀ mode in a guide of cross section $a \times b$ has fields that can be written (in Gaussian units) as $E_x = 0$, $E_y = E_0 \sin \pi x/a$, $E_z = 0$, $H_x = - (ck_g/\omega)E_y$, $H_y = 0$, $H_z = -i(\pi c/a\omega)E_0 \cos \pi x/a$, with the dispersion relation $\omega^2 = k_g^2 c^2 + (\pi c/a)^2$. The positive $(\pi c/a)^2$ could be interpreted as a mass term but again a waveguide is not really a vacuum state in nature. In order to incorporate the dispersion result in a theory of scalar matter wave, the Klein-Gordon eq in 1926, an extension from the Maxwell scalar equation with an extra term, could be used. The Klein-Gordon equation $\Delta \Psi = (1/c^2) \partial(\partial\Psi/\partial t)/\partial t + (m^2 c^2/\hbar^2) \Psi$ has the correct dispersion relation $\omega^2 = k^2 c^2 + m^2 c^4/\hbar^2$ such that the mass term is positive (Klein & Gordon, 1926).

Yukawa proposed that the extra term mass would stand for the meson exchange in nuclear force and the short range is given by the Compton wavelength (Yukawa 1935). The details that the Yukawa potential, which is proportional to $(1/\text{distance}) * \exp(-\text{constant} * \text{mass} * \text{distance})$, a screened Coulomb potential function, is the Green function of the Klein-Gordon equation would be taught in an upper college course in calculus beyond community college. Anyway the important event is the Yukawa (1950a, 1950b) extensions which included the reverse interpretation that an interacting field can be represented by a mass particle; and that Higgs field has a Higgs boson. There is a mechanical model for analogy. Consider a string with tension in the x-axis. The attachment of tiny springs (spring constant K) in the y-direction would result in the follow equation $T * d(dy/dx)/dx - Ky = \rho * d(dy/dt)/dt$ with dispersion relation $\omega^2 = k^2 v^2 + K/\rho$. The derivation can be obtained by plugging a standard wave solution, $\text{Constant} * \exp(-i(ky - \omega t))$, into the wave equation. The calculus steps and its analogy to quantum tunneling are available on the open web as lecture notes (Morin 2015). The K/ρ is a mass given to the wave if the amplitude of these waves is tiny with small energy perturbation given by spring-like interaction with vacuum. And this is the Yukawa-Higgs boson connection, so to speak at the community college physics level. However, there is one last question, namely, "How would vacuum, the lowest energy state, sustain such perturbation?"

Spontaneous Symmetry Breaking supports small oscillation at non-zero field value

How would vacuum, the lowest energy state, sustain a perturbation? The explanation would come from in another concept, symmetry breaking in a potential $V(\phi)$ such that ϕ has a value other than zero for V- minimum. After all V-minimum at $\phi = 0$ would give zero value for the Higgs boson mass. The situation can be summarized in the UK Science Minister One-page Writing Competition on Higgs mechanism. In 1993, the UK Science Minister, William Waldegrave, challenged physicists to produce an answer that would fit on one page to the question 'What is the Higgs boson, and why do we want to find it?' (Butterworth et al 2011)

"Excerpt: (Higgs) starts with a particle that has only mass, and no other characteristics, such as charge, that distinguish particles from empty space. We can call his particle H. H interacts with other particles; for example, if H is near an electron, there is a force between the two. H is of a class of particles called "bosons". ... Higgs found that parameters in the equations for the field associated with the particle H can be chosen in such a way that the lowest energy state of that field (empty space) is one with the field not zero. It is surprising that the field is not zero

in empty space, but the result, not an obvious one, is: all particles that can interact with H gain mass from the interaction. Thus mathematics links the existence of H to a contribution to the mass of all particles with which H interacts. A picture that corresponds to the mathematics is of the lowest energy state, “empty” space, having a cloud of H particles with no energy of their own. Other particles get their masses by interacting with this collection of zero-energy H particles. The mass (or inertia or resistance to change in motion) of a particle comes from its being “grabbed at” by Higgs particles when we try and move it.”

Translating the crucial writing “It is surprising that the field is not zero in empty space” into a physics class, the learning would become “How to analyze the lowest energy state in a system?”. Take a bead object sitting on a circular smooth hoop that rotates at angular speed ω . Without rotation, the bead would sit at the lowest hoop position such that $\theta = 0$. Once the rotation starts, the lowest energy would not be $\theta = 0$ for high ω values. Conceptually students would usually learn the apparent weight concept via reaction force changes in elevator example, roller coaster example and road bank curve example. The road bank curve example shows that the normal reaction N is larger than the weight mg such that $N \cos(\theta) = mg$, unlike in the more familiar incline plane case where $N = mg \cos(\theta)$. Anyway a rotating frame is a non-inertia frame so that there is an additional pseudo-centrifugal force $mR \sin\theta \omega^2$ when applying Newton’s Second Law. Note that the gravity contribution to the motion along the hoop wire would be the usual sine component equal to $mg \sin\theta$ (downward pointing along the hoop wire); and the outward pseudo-centrifugal force contribution to the motion along the hoop wire would be a cosine component equal to pseudo-centrifugal force $\times \cos\theta$ (upward pointing along the wire hoop).

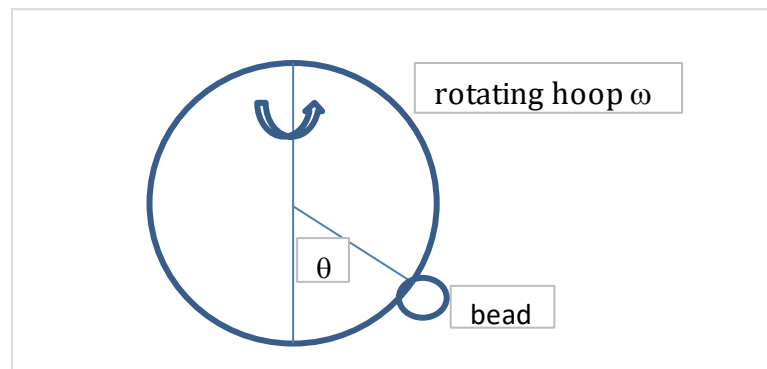


Figure 6: A bead is free to slide on a circular wire hoop, of radius R , which rotates at ω

The regular pendulum equation without a rotating hoop $m \frac{d}{dt}(R \frac{d\theta}{dt}) = -mg \sin\theta$ which is a standard problem in calculus physics small angle. In the rotating hoop case, the equation would acquire an additional pseudo-centrifugal force term such that

$$m \frac{d}{dt}(R \frac{d\theta}{dt}) = -mg \sin\theta - mR \omega^2 \sin\theta \cos\theta \text{ in a frame rotating at } \omega.$$

Using the Lagrangian approach (Harr 2008) of course would yield the same equation of motion in the teaching of a fourth semester Analytical Mechanics course in a community college.

$KE = (1/2) mR^2 [(\frac{d\theta}{dt})^2 + \omega^2 \sin^2\theta]$, knowing $R \sin\theta \omega$ as the additional velocity to the sliding up and down with the usual $R \frac{d\theta}{dt}$ velocity

$$PE = mgR (1 - \cos \theta)$$

Using $L(\theta, \dot{\theta}) = KE - PE$ and $\partial L / \partial \theta = d(\partial L / \partial \dot{\theta}) / dt$ will give the same equation of motion as using Newton Second Law in a rotating frame with a pseudo-centrifugal force.

The equation $d^2\theta/dt^2 = (\omega^2 R \cos \theta - g/R) \sin \theta$ is not easy to solve. If $\omega = 0$, no rotation case, the equation would become the usual pendulum equation $d^2\theta/dt^2 = - (g/R) \sin \theta$. When the hoop is rotating, there is a new equilibrium position θ_0 such that $d^2\theta/dt^2 = 0 = (\omega^2 R \cos \theta - g/R) \sin \theta$

Therefore, when $(\omega^2 R \cos \theta - g/R) = 0$, the $\theta_0 = \arccos (g / \omega^2 R)$ at positive and negative values would be the equilibrium position supporting small oscillations ϵ such that $\theta = \theta_0 + \epsilon$.

A standard fourth semester introductory quantum mechanics would cover quantum harmonic oscillator but the second quantization for phonon excitation is not taught till a student transfers to a senior college. Our community college students can still visualize the oscillation associated bosons (called the Higgs bosons when the field is the Higgs' field) with their fluid intelligence after they learned Planck's treatment of blackbody radiation as a photon gas inside a cavity. Both photon and phonon are bosons and obey the Bose-Einstein Statistics.

We can write $L = (1/2) m R^2 [(d\theta/dt)^2 + PE_{eff}]$ so that $PE_{eff} = mgR (1 - \cos \theta) - (1/2) m R^2 \omega^2 \sin^2 \theta = mgR(1 - \cos \theta - (\omega^2/2g)\sin^2 \theta)$

A schematic illustration of two potential curves is displayed with off-centered minimum in Figure 7, a spontaneous symmetry breaking situation when the bead sits on the left $-\theta_0$ or right side $+\theta_0$ of the rotating hoop, when the PE function is symmetrical for $+\theta$ going to $-\theta$. Interestingly for small θ , the PE function can be written as $mgR(A/2) \theta^2 + mgR(B/6) \theta^4$ with $B = \omega^2 / \sqrt{g/R}$ and $A = 1 - B^2$. Note that the expression of PE_{eff} in θ^2 and θ^4 is the same expression used in the Lagrangian treatment of the Higgs field; where the θ^2 term is related to small oscillation around the potential minimum θ_0 and thus avoid the interpretation of having a negative mass given spontaneous symmetry breaking, and the θ^4 term is related to the four-point self-interaction in field theory. Anyway this classical analogy shows that a lowest energy state can sustain a perturbation around a non-zero θ value and provides further understanding to the prize winning essay containing the description: "Higgs found that parameters in the equations for the field associated with the particle H can be chosen in such a way that the lowest energy state of that field (empty space) is one with the field not zero (Butterworth et al 2011)."

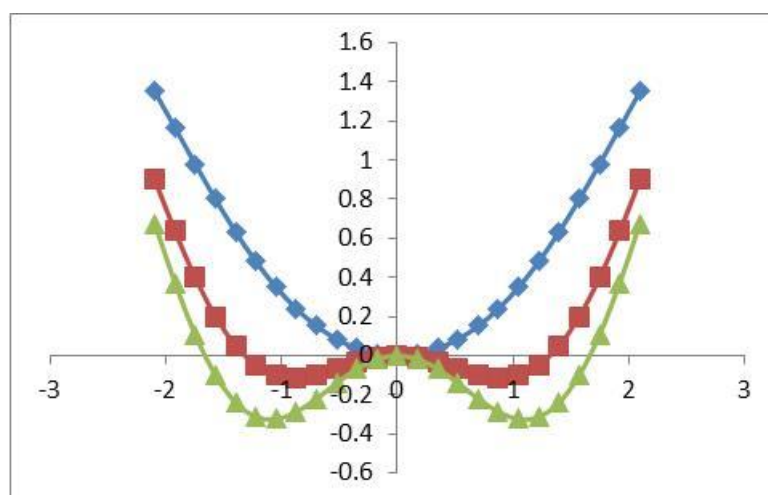


Figure 7. Schematic illustration of PE_{eff} (y-axis) as a function of θ (ξ -axis) in arbitrary units. Note that larger $\omega^2/2g$ values would give θ_{min} at non-zero values.

DISCUSSION

Hindsight is always 20-20 but it would be instructive to include the in-between connections, from the Yukawa meson theory in 1935 to the Higgs boson confirmation in 2013, for the very few physics student majors in a community college class. The symmetry breaking concept pioneered by Nambu (Nambu 1960), followed by Schwinger (Schwinger 1962), and the application to Electroweak as the initial success of the Brout-Englert-Higgs mechanism could be included (Higgs 1964a, 1964b, Brout & Englert 1964). The Higgs field and its boson verification were verified much later in 2013. For the Higgs field incorporation explanation, complex variable analysis would be needed in an upper college level beyond community college. Basically the complex notation is needed to keep track of the two orthogonal components in the Lagrangian; just like phasor complex notation in calculus physics for 90-degree out of phase analysis (Vulpen et al 2011).

Intelligence has been classified into several subcategories including fluid intelligence, crystallized intelligence, and emotional intelligence. In a physics classroom, the development of fluid intelligence and crystallized intelligence are of the most concern when peer learning is excluded. A recent throughout summary of fluid intelligence and crystallized intelligence can be found in a 2011 open access dissertation (Postlethwaite 2011). The study on the influence of schooling on fluid intelligence and crystallized intelligence can be dated back to the early work of Kaufman et al in 1996 (Kaufman et al 1996), which showed that crystallized intelligence appears to increase from schooling to about 20 years old and not to decline until around 60 years old. In contrast, fluid intelligence would decline over the entire adulthood with obvious decline acceleration beginning at about 55 years old. A following report from Yale School of Medicine in 2009 showed that the correlation of fluid intelligence to schooling is just as strong as the correlation of crystallized intelligence to schooling (Kaufman et al 2009). And furthermore, the Yale data showed that math correlates higher with years of formal schooling than reading or writing. Recent 2015 psychological intelligence test data (Saliasi et al 2015) and financial decision test data (Li et al 2015) on aging studies also showed that higher crystallized intelligence from education would provide intellectual capital after 60 years old. In general, it is accepted that crystallized intelligence, the application of general and domain specific knowledge, would increase with age till 60 years old. The concept of mass increase with lower speed is not difficult to

understand especially with numerical examples as described above. The extension to object like photon could follow the same relationship of increased speed with decreased mass, a crystallized intelligence in classical mechanics. A few students would even propose that light must gain mass when being slowed down inside glass such that the case of apparent mass for a massless particle could be solved easily.

However, this simple mass increase with lower speed is not applicable to photon. As early as 1925, de Broglie showed that this extension would have a negative mass according to the resulting dispersion relation expression. The remedy in using the Klein- Gordon equation proposed in 1926 and the string with vertical spring analogies would strengthen fluid intelligence whereas the derivation procedure of plugging a standard wave solution to the differential equation to obtain a dispersion relation would strengthen crystallized intelligence. The spontaneous symmetry breaking mechanism supporting a non-zero field value at a minimum energy state can be visualized via object oscillatory sliding along a rotating hoop example which would broaden fluid intelligence. This one time learning on non-inertia frame mechanics via a simple Lagrangian for students not taking Analytical Mechanics in their fourth semester could be classified as one-shot learning where the hippocampus would be selectively switched on by the ventrolateral prefrontal cortex (Lee et al 2015). Student discussion and responses are valuable data for physics education research assessment. A professor's teaching effectiveness could be measured by their students' grades in later courses and such measure of teacher effectiveness with students' evaluations has been conducted. The results showed that the better the professors were, as measured by their students' grades in later classes, the lower their ratings from students (Braga et al 2014). Although it would be difficult for a community college assessment to be designed with data from senior colleges where the students would transfer to, the crystallized intelligence learned within a community college would still be assessable. An assessment rubric for crystallized intelligence in terms of energy budget calculation, dispersion relation derivation, pseudo- force in non- inertia frame, Lagrangian approach, and small oscillation approximation is shown below.

Participant Deliverable	Highly Competent	Competent	Needs Improvement
Numerical checking of energy budget (25%)	Calculates the energy budget correctly with each energy item fully explained	Calculates the energy budget incorrectly due to one mistake in arithmetic	Calculates the energy budget incorrectly due to two or more mistakes
Dispersion relation derivation (25%)	Reproduces the derivation correctly when given different symbols in a quiz	Reproduces the derivation approximately when given different symbols in a quiz	Fails to reproduce sensible expressions when given different symbols in a quiz
Rotating loop derivation using non-inertia frame pseudo- centrifugal force (20%)	Applies the concept of pseudo-force successfully with the correct vector expression in a rotating loop along different x or y or x axis	Applies the concept of pseudo- force successfully with the correct scalar expression but wrong force direction in a rotating loop along different x or y or x axis	Fails to write any sensible expressions for the pseudo- force in a in a rotating loop along different x or y or x axis
Rotating loop derivation using Lagrangian approach (5%)	Applies the calculus skill correctly and explains each term in the equation of motion from the Newton's Second Law concept as well	Applies the calculus skill correctly but cannot explain each term in the equation of motion from the Newton's Second Law concept	Applies the calculus skill incorrectly and obtains the wrong equation of motion
Small oscillation approximation (25%)	Applies the small oscillation approximation with small angle expansion and obtains the correct potential curve for a given set of input parameters	Applies the small oscillation approximation with small angle expansion and obtains a potential curve with one error for a given set of input parameters	Fails to apply the small oscillation approximation and does not understand small angle expansion

Figure 8. An assessment rubric for crystallized intelligence

CONCLUSIONS

The teaching principle of supplementing News Media with course materials has been implemented in physics courses at the community college level. The Higgs boson confirmation news triggered the lesson deliveries of examples in apparent mass increase with internal motion, dispersion relation with an additional term being interpreted as mass, and the spontaneous symmetry breaking consequence that would support small oscillation (bosons) at the lowest energy non-zero field state via a one time teaching of the Lagrangian. Model analogy strategy has been used to strengthen fluid intelligence development. Derivation steps and their understanding have been attributed to crystalized intelligence practice and an assessment rubric has been developed. The development of new examples and the study of the effectiveness of one-shot learning versus incremental learning would be interesting projects for future investigations.

SUPPLEMENT MATERIALS

Two videos are shown. The Pendulum-car video shows data that the car moves a lesser distance when compared to the data in the Sitting-pendulum video. The Physics & Astronomy Education Research Group at Rutgers University using two

equal mass objects via the Atwood machine setup also shows that a swinging motion would cause the two equal mass objects to move (<http://paer.rutgers.edu/PT3/experiment.php?topicid=13&exptid=153.>)

ACKNOWLEDGEMENTS

We thank the scientists and institutions sharing their materials online.

REFERENCES

- Bragaa, M., Paccagnella, M., & Michele P., (2014). Evaluating students' evaluations of professors Economics of Education Review Volume 41, August 2014, Pages 71–88 <http://www.sciencedirect.com/science/article/pii/S0272775714000417>
- Butterworth, M., Butterworth, I., Teplitz, D., & Teplitz, V., (2011). How Particles Acquire Mass. Physics World Volume 6 Number 9 <http://physicsforme.wordpress.com/2011/07/24/higgs-boson-one-page-explanation/>
- Chen X., (2015) STEM Attrition among High Performing College Students in the United States: Scope and Potential Causes Journal of Technology and Science Education. Vol 5(1), 2015, pp 41 <http://www.jotse.org/index.php/jotse/article/view/136/150>
- Broglie D., (1925a), Louis On the theory of quanta, (a translation of the thesis of de Broglie, "Recherches sur la théorie des quanta", trans. by A.F. Kracklauer), Ann. de Phys., 10e serie, t. III, (1925) http://dieumsnh.qfb.umich.mx/archivoshistoricosMQ/ModernaHist/De_Broglie_Kracklauer.pdf <http://dieumsnh.qfb.umich.mx/archivoshistoricosMQ/>
- Broglie D., (1925b), Louis. Sur la fréquence propre de l'électron, Comptes rendus 180, p. 498-500, (1925). http://dieumsnh.qfb.umich.mx/archivoshistoricosMQ/ModernaHist/180_498.pdf <http://dieumsnh.qfb.umich.mx/archivoshistoricosMQ/>
- Englert, F., & Brout, R. (1964). Broken Symmetries and the Mass of Gauge Vector Bosons, *Phys. Rev. Lett.* 13, 321
- Gordon, W (1926), Der Comptoneffekt nach der Schrodingerschen Theorie, Zeit. Phys. 40, 117
- Harr, R., (2008) A Bead on a Spinning Wire <http://hep.physics.wayne.edu/~harr/courses/5210/w08/lecture18.htm>
- Higgs, P.W. (1964a) Broken Symmetries, Massless Fields and Gauge Bosons, *Phys. Lett.* 12, 132
- Higgs, P.W. (1964b) Broken Symmetries and the Masses of Gauge Bosons, *Phys. Rev. Lett.* 13, 508
- Kaufman, A.S., Kaufman, JC, Liu, X, & Johnson, CK. (2009). How do educational attainment and gender relate to fluid intelligence, crystallized intelligence, and academic skills at ages 22-90 years? *Arch Clin Neuropsychol.* 2009 Mar;24(2):153-63 <http://www.ncbi.nlm.nih.gov/pubmed/19185449>
- Kaufman, A.S., & Horn, J.L. (1996). Age changes on tests of fluid and crystallized ability for women and men on the Kaufman Adolescent and Adult Intelligence Test (KAIT) at ages 17-94 years. *Arch Clin Neuropsychol.* 1996;11(2):97-121. <http://www.ncbi.nlm.nih.gov/pubmed/14588911>
- Klein, O (1926), Quantentheorie und funfdimensionale Relativitatstheorie, Zeit. Phys. 37, 895
- Kovas et al & 25 co-authors (2015) Why children differ in motivation to learn: Insights from over 13,000 twins from 6 countries. *Personality and Individual Differences* Volume 80, July 2015, Pages 51–63 <http://www.sciencedirect.com/science/article/pii/S0191886915000987>
- Lee, S.W. O'Doherty, JP, & Shimojo, S. (2015). Neural computations mediating one-shot learning in the human brain. *PLoS Biol.* 2015 Apr 28;13(4):e1002137 <http://www.ncbi.nlm.nih.gov/pubmed/25919291>
- Leinweber, D., (2013). Your Mass is NOT from Higgs Boson <http://www.youtube.com/watch?v=Ztc6QPNUqls> <http://www.physics.adelaide.edu.au/theory/staff/leinweber/>

- Li, Y., Gao, J., Enkavi, A.Z., Zaval, L., Weber E.U., & Johnson E.J., (2015). Sound credit scores and financial decisions despite cognitive aging. *Proc Natl Acad Sci U S A*. 2015 Jan 6;112(1):65-9. <http://www.ncbi.nlm.nih.gov/pubmed/25535381>
- Morin, D., (2015). Waves Lecture Notes: Chapter 6 Dispersion Section 6.2.2 Low-frequency cutoff equation 19 & Chapter 10 Introduction to Quantum Mechanics Section 10.3.4 Tunneling <http://www.people.fas.harvard.edu/~djmorin/waves/dispersion.pdf>
<http://www.people.fas.harvard.edu/~djmorin/waves/quantum.pdf>
- Nambu, Y. (1960). Quasi-Particles and Gauge Invariance in the Theory of Superconductivity, *Phys. Rev.* 117, 648.
- PhysicsNet (2015) Mass and energy <http://physicsnet.co.uk/a-level-physics-as-a2/nuclear-energy/mass-and-energy/>
- Postlethwaite, B.E. (2011). Fluid ability, crystallized ability, and performance across multiple domains: a meta-analysis. University of Iowa Dissertation <http://ir.uiowa.edu/etd/1255/>
- Rifkin, T., & Georgakakos, J.H., (1996). Science Reasoning Ability of Community College Students. ERIC Digest. ERIC Identifier: ED393505 Publication Date: 1996-03-00 <http://www.ericdigests.org/1996-4/science.htm>
- Saliasi, E., Geerligs, L., Dalenberg, J.R., Lorist, M.M., & Maurits, N.M., (2015). Differences in cognitive aging: typology based on a community structure detection approach. *Front Aging Neurosci.* 2015 Mar 19;7:35 <http://www.ncbi.nlm.nih.gov/pubmed/25852549>
- Schwinger, J. (1962). Gauge Invariance and Mass, *Phys. Rev.* 125, 397
- Vulpen, I., & Castelli, A., (2011). The Standard Model Higgs Boson: Part of the Lecture Particle Physics II, UvA Particle Physics Master 2011-2012 <http://particles.nl/LectureNotes/2011-PPII-Higgs.pdf>
- Yukawa, H., (1935). On the Interaction of Elementary Particles. I., *Proc. Phys.-Math. Soc. Japan* 17, 48
- Yukawa, H., (1950a). Quantum Theory of Non-Local Fields. Part I. Free Fields, *Phys. Rev.* 77, 219 (1950)
- Yukawa, H., (1950b). Quantum Theory of Non-Local Fields. Part II. Irreducible Fields and their Interaction, *Phys. Rev.* 80, 1047 (1950),

