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Individual Articles

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The International Council on Materials Education (the Publisher of JME), and the Editors of the Journal are pleased to announce that the Journal of Materials Education has been accepted for coverage by

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- ***ISI Alerting Service***
- ***Materials Science Citation Index (MSCI).***

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We consider that such archival coverage is very appropriate for JME, in the light of the consistently high quality of the papers accepted for publication following careful peer review, and their topical relevance for the healthy progress of the Materials Education field.

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Finally, we wish to compliment all those authors whose great work over the 33 years of the Journal's activity has laid the solid foundations for this significant professional recognition.

\- *The Editors of JME.*

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A MATERIALS SELECTION AND DESIGN PROCEDURE FOR SELECTION OF AUTOMOBILE VEHICLES THAT ARE ENVIRONMENTALLY FRIENDLY IN TERMS OF AVAILABLE ENERGY RESOURCES

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ABSTRACT

The present review focuses on determining the environmental burden throughout the service life of a certain automobile component. Design of such a component is associated with the selection of a candidate material that optimizes its structural properties while simultaneously minimizing its weight, the energy involved in its manufacture and the energy consumed during its service life. The analysis establishes a simple routine inspection method that allows engineering students to make an overall decision in terms of the choice among a range of available materials; the design choice has priority among pre-established requirements.

Two groups of vehicles with middle to high price range are compared, with different engines: Diesel, gasoline and hybrid. One class consists of off-road vehicles, the other of comparable on-road sedans.

Undergraduate students in their second and third year of the Industrial Technical Engineering program at the University of Oviedo have evaluated variations such as changes in the choice of the material, the car components and car models. Students worked in teams and were told to pay attention to “green engineering”. Instructors involved have been able to confirm that significant learning was achieved.

Keywords: *automobile manufacturing, lifetime energy consumption, ecodesign, sustainable materials design, greenhouse effect index, service life.*

NOMENCLATURE

A	=	Area
a	=	Crack depth (length)
b	=	Width of the sheet
c_S	=	Specific energy consumption
E	=	Young's modulus
e_S	=	Specific emission
e_T	=	Total emission
F	=	Uniformly distributed force
GHE	=	Greenhouse effect
I	=	Second moment of inertia
K_{IC}	=	Plane strain fracture toughness
LEC	=	Lifetime energy consumption
L	=	Length of the sheet
M	=	Mass of bonnet [U.S.: hood]
K_i	=	Mass related merit index
q	=	Energy content of the material
t	=	Thickness of the sheet
w	=	Weight of the vehicle
y	=	Distance from the end or edge of the section to the neutral line
Y	=	Dimensionless parameter in Griffith's equation
δ	=	Elastic deflection under load
ρ	=	Mass density
Γ	=	Deflective moment
σ_y	=	Yield stress

1. INTRODUCTION

The automobile industry is redefining its products through enhanced engine performance as well as through the development of new models that should be more comfortable, safer, easier to drive and more environmentally friendly. All these goals are achieved by simultaneously employing different eco-design engineering methods ranging from materials selection all the way to treatment of the vehicle at the end of its service life. This novel approach to design supposes a new way of integrating environmental criteria in product development as a competitive element in manufacturing strategies. Ecodesign practices are changing the way in which automobiles are conceived and oblige companies in the automobile industry to embrace – and even anticipate – restrictive environmental regulations. Within this context, environmental policies have become an important criterion for materials selection. Clean, recyclable materials are responsible for the environmental quality of the automobile, which is in the process of becoming a critical aspect for the not-too-distant future [1].

Ecodesign is sometimes referred to as Clean Design, Design for the Environment (DFE) or Sustainable Design, indicating that the term first named is still not clearly defined or very well known. The most important aim of Clean Design is to minimize air pollution and often refers to "green car technologies" [2] in terms of their low or zero pollutant emissions. In contrast to this concept, Ecodesign consists in performing environmentally friendly design activities from the first phase of the project for a product through to its production and consumption phases [3]. In recent times, this last phase has been extended to include recycling of the product - once it has reached the end of its service life. Ecodesign is set to form part of the environmental criteria of product design and development projects. This means that, within the context of environmental equilibrium criteria, it will also take into account basic project requirements such as cost, safety and time span from the moment the product is conceived up until it is produced and may be used efficiently by the consumer. Eventually, one expects that even dismantling and recycling stages will be included.

Eco-designing a product as complex as an automobile component, implies minimizing its environmental impact over its entire service life. This is no easy task - bearing in mind that such a project must also be carried out in compliance with environmental legislation such as Directive ELV and ISO 14000 [4] in the case of European automotive companies.

Green engineering principles should be familiar to and used by all engineers, and the need to introduce the concepts to undergraduate students has become increasingly important [5 - 8]. Practice of an engineering profession often implies teamwork; engineers should become accustomed to this way of operation. Such a training should begin early, but in earlier syllabuses remained dormant; students continued their training at colleges and engineering schools such that teaching and learning styles evolve around lecture-based activities. Very little attention was traditionally paid to helping students to develop the necessary skills for successful teamwork as a prospective professional tool - until it was recognized that students can learn more effectively when actively involved in the learning process [9, 10]. The case study approach is an active learning methodology consisting of solving somewhat complex examples - which provide a clear understanding of a problem as well as illustrating the main points [11, 12]. Until recently, instructors in engineering disciplines have *not* been encouraged by their academic authorities to develop active learning methodologies such as case studies in class. In this situation, in the present article we propose a case study to aid instructors in the development of a teamwork-based learning methodology that has been applied to Industrial Technical Engineering students at the University of Oviedo (Fig. 1). The chosen case study explores “Green Car Engineering Design”. Bearing in mind the subject matter addressed, two subjects from the curriculum were considered as the vehicle with which to implement the experience in its most successful way: “Materials Selection in Mechanical Design” belonging to the “Mechanical Engineering” program and “Metallic Materials” belonging to “Industrial Chemistry” study program. The case study provided to students was solved by teams consisting each of 3 or 4 students. The students were required to provide up a written report and also to present and defend their work orally in class [13].

As a result of the learning methodology, the student develop specific competencies (technological skills) as well as related competencies such as: communication skills (non-verbal, written, oral, multimedia) and also teamwork skills (negotiation, arguing and mediating in conflicts), besides developing personal skills (empathy, confidence, self-conscience and adaptation and initiative capacities) [14, 15]. In short, our proposed case study has allowed students to discover materials for a given application, to carry out the analysis that enables them to identify those materials and components which are more environmentally friendly, and to rank them according to their suitability in this respect [16].

2. EXPERIMENTAL PROCEDURE

The method followed in the development of our study is explained in this Section according to the different stages shown in Fig. 2, including the vehicles to consider, their different types of bodywork and engine mounts, the chosen part of the bodywork and the material employed.

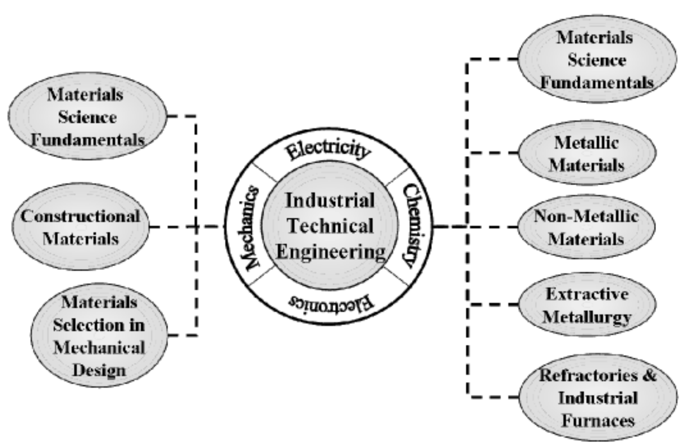

Figure 1. Industrial Technical Engineering courses in which the learning methodology has been implemented at the University of Oviedo.

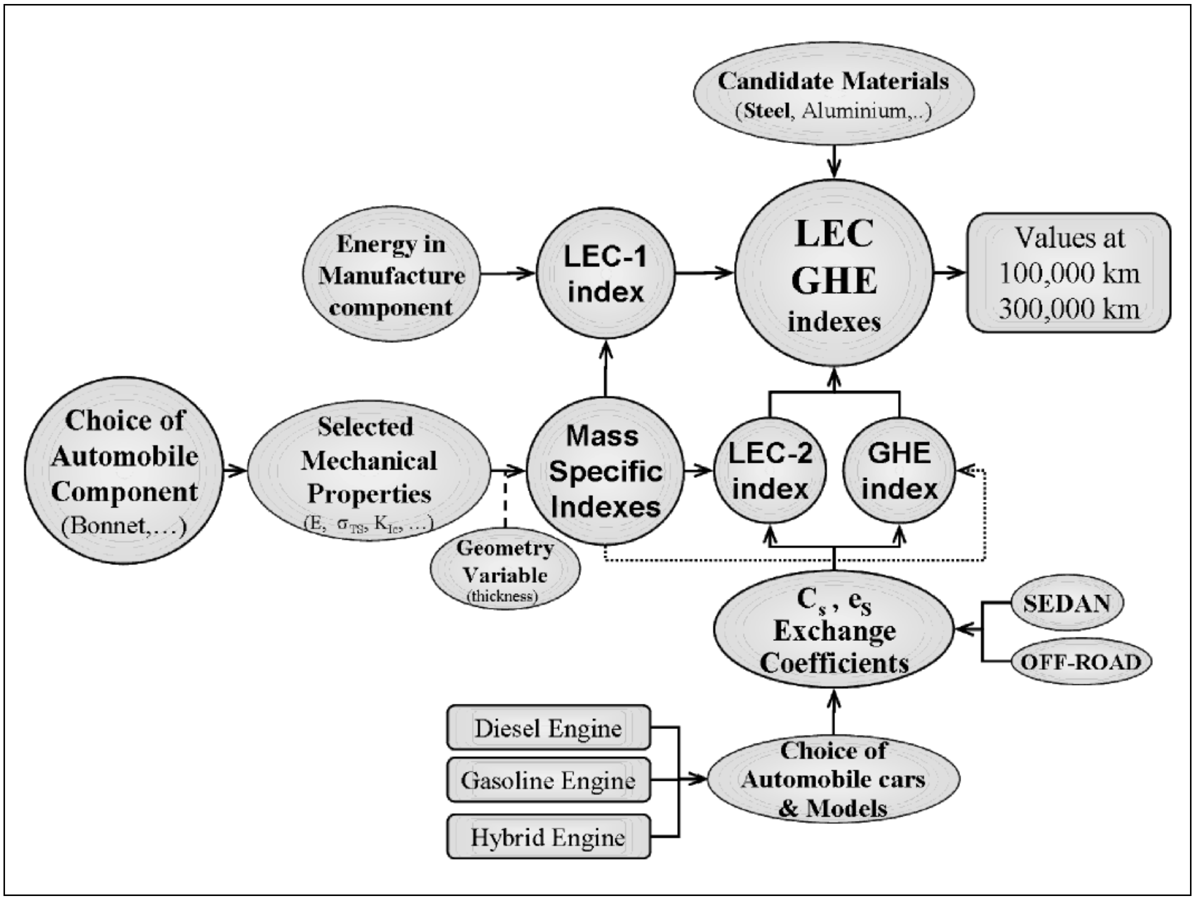

Figure 2. Schematic diagram describing the different stages and calculations in the presented methodology.

2.1. Design Process

The design process is approached from a dual perspective in the present study. On the one hand, we focus on the energy consumption used to obtain the final shape of the automobile component starting out from the chosen raw material. On the other hand, preferential attention is paid to the energy consumed throughout the service life of the vehicle, taking into account the different types of car models.

A. Steel

Low density structural materials that are of interest for the transport industry usually tend to be expensive, a result of a transformation process that starts out from the corresponding raw material. A clear-cut example of this problem consists of metal alloys of aluminium, titanium, magnesium or beryllium. The same occurs with polymers, ceramic materials and composites such as those containing epoxies or Kevlar. This high cost usually means that higher density materials are used to reduce manufacturing costs, although these materials increase usage and maintenance costs considerably. While heavier materials are relatively cheap and abundant due to the widespread existing industrial infrastructure, they do not provide the same features as their low density counterparts. An outstanding example of this consists of the process of selecting materials for their use in the transport industry (automobile, aeronautical and maritime), where an increase in the mass of the vehicle will lead to an increase in fuel consumption throughout the service life of the system.

Steel constitutes a clear-cut example of this commonplace phenomenon in the processes of selecting materials for structural applications. Despite not achieving the structural properties of some of its competitors, iron's abundance in the earth crust and the deployment of a widespread production technology able to develop a broad range of iron-based alloys has led to much lower manufacturing costs with respect to its competitors - affording it a major competitive edge over materials better positioned in terms of density [17 - 25]. Ferrous materials are energy burdens during their service life on account of their relatively high densities.

Owing to the gamut of properties that steel possesses as a structural material and its extensive present-day use in the automobile industry, steel was the material chosen.

The properties of the chosen steel are shown in Table I, where the relevant data for the 2024 aluminium alloy is also provided as an alternative material to steel. Among the properties presented here, the energy content *q* is of special relevance due to the nature of our study. All materials effectively "contain" energy, which is used to extract the raw material and transform and shape the material. When we use a material, we are using energy - an environmental burden that has to be taken into consideration. Energy constitutes only one of the eco-influences on production and use of the material, but it is easier to quantify than other aspects such as formation of byproducts. Steel provides low environmental impact; its production technology is highly developed, both in terms of manufacturing and recycling, and it is less environmentally harmful than, for instance aluminium - one of main rivals of steel in the automobile industry.

Table I. Structural and functional properties for the HSLA steel and an aluminium alloy, as prospective candidate materials for a car bonnet.

	E [GPa]	**σ_y** [MPa]	**ρ** [T/m^3]	**K_{IC}** [MPa·m$^{1/2}$]	**q** [MJ/kg]
HSLA steel	210	600	7.85	110	66
Al 2024-T6	72.4	414	2.7	31	285

Table II. Sedan and off-road vehicle characteristics for each of the car models considered in the study (extracted from manufacturers brochures)

	Name	**Engine**	**Cubic Capacity** (cm^3)	**Power** (HP)	**Weight** (kg)	**Consumption** (l_{fuel}/100Km)	**Pollutant Emissions** (g CO_2/km)
Sedan	***Diesel 1***	Diesel	2967	233	1720	7.11	189
	Diesel 2	Diesel	2993	235	1665	6.9	184
	Hybrid	Hybrid	3456	296	2355	7.9	185
	Gasoline	Gasoline	2995	249	2125	9.8	232
	Diesel 3	Diesel	2987	224	1815	7.9	212
Off-Road	***Diesel 1***	Diesel	2967	233	2250	10.5	282
	Diesel 2	Diesel	2993	235	2170	8.6	229
	Hybrid	Hybrid	3311	211	2505	8.1	192
	Gasoline	Gasoline	3456	276	2380	11.2	264
	Diesel 3	Diesel	2987	224	2185	9.8	260

Vehicles used in the study

Table II [26 - 30] presents the features of the vehicles that were selected for this study, the values of which were directly provided by the manufacturers to ANFAC (Spanish Automakers Association). All models belong to the mid-high range of the automotive industry. Two models are analysed in each make: an off-road vehicle and its sedan equivalent. The power sources in the models studied include Diesel engines - popular in Europe - as well as hybrid engines (gasoline + electric) and gasoline engines. The material of the chassis in all the chosen models is steel.

B. Component under study

Within the vehicle bodywork, the bonnet was chosen as the structural element for reasons of simplicity in the stress analysis. This was considered to be a simply supported sheet of metal with the load uniformly distributed over its upper face (Fig. 3) in order to derive merit indexes for each chosen mechanical property on the basis of the Materials Selection method proposed by Ashby [31, 32]. The auto body component considered in this study (car bonnet) and the methodology of analysis followed have been described in our earlier article [33].

We now describe how the system constraints with respect to one or other of the properties under investigation are determined. After establishing a variable in the geometry of the solid for which a constraint will be defined, such as the thickness *t*, we then obtain an integrative equation which includes two terms: the so-called fixed term referring to dimensions

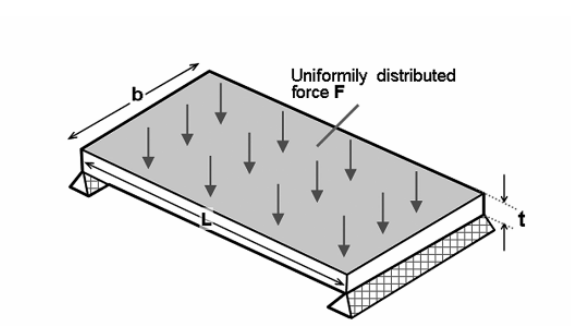

Figure 3. A simply supported sheet of metal with the load uniformly distributed over its upper face.

and known constraints; and the variable or material's term, which may be expressed in the form of a merit index. The merit index provides a numerical value for each material and may be maximized or minimized depending on the system constraint.

As noted above, our approach included density as well as mechanical properties, bearing in mind that the upper face supports the pressure of wind, water or snow and hence must be resistant to deformation. The mechanical design must allow a certain capacity of absorption of elastic energy without exceeding the elastic limit of the material, for example in occasional impacts on its surface (hail, stone projectiles, minor collisions, etc.).

<u>Design for rigidity</u>

A study of the elastic deflection of the geometry is carried out first so as to calculate the mass related merit indexes on the basis of this factor.

We first obtain the maximum deflection (Fig. 4), bearing in mind that the applied force F uniformly distributed over the surface of the bonnet corresponds to a single pressure taking the value p = F/bL situated in its center of gravity (see the Nomenclature list).

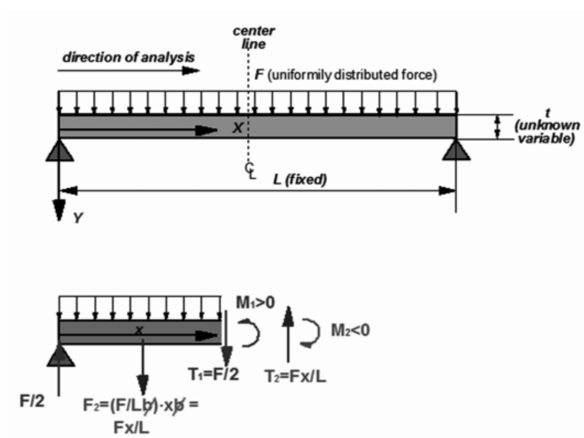

Figure 4. Diagram of stresses and moments.

From the diagram in Fig. 4, we formulate the following equation based on the momentumcurvature equation [34]:

$$(EI)y'' = -M = -\left(\frac{Fx}{2} - \frac{Fx^2}{2L}\right) = \frac{Fx^2}{2L} - \frac{Fx}{2} \qquad (1)$$

This equation has to be integrated twice. First we calculate the constant C_1, bearing in mind that there is no change in slope at $x = L/2$ and hence at that point $y' = 0$. The value of the constant C_2 resulting from integrating a second time is obtained establishing the boundary condition that the deviation of the sheet is zero at the support ($x = 0$).

Substituting in the equation resulting from these two integrations the fact that the value of the deflection is maximum ($y = \delta_{max}$) in the middle of the sheet ($x = L/2$), we obtain the maximum deflection value for this setup:

$$\delta_{\max} = \frac{5FL^3}{24 \times 16 \times EI} \qquad (2)$$

We consider here the axis of rotation in bending perpendicular to the sheet and in the middle of the sheet. That is, we are dealing with the second moment of area of the cross-section I_z. Retaining however the symbol I, we have

$$I_z = I = \frac{bt^3}{12} \qquad (3)$$

which, when substituted into Eq. (2), allows us to obtain the definitive value for the maximum deflection - which shall then be used to calculate the merit index:

$$\delta_{\max} = \frac{5FL^3}{32Ebt^3} \qquad (4)$$

The rigidity of a metal sheet that is subjected to bending is represented here by Young's modulus *E* and depends on the cross-sectional geometry (*b* and *t*) of the sheet - taken into account in its second moment of inertia *I*. In this approach to the problem, the goal is to find a sheet of variable thickness *t* while seeking to minimize its mass *M*. At the same time, the system constraint related to rigidity must also be taken into consideration, *i.e.* the elastic deflection δ cannot surpass a certain value within the elastic field δ_{max} as expressed below in Eq. (6). The equations for mass of the sheet *M* and for the imposed mechanical constraint are expressed – via the application of the approximate equation of the elasticity of continuous beams – by

$$M = \rho L b t \qquad (5)$$

$$\delta \le \delta_{máx} = \frac{5FL^3}{32Ebt^3} \qquad (6)$$

As stated, the thickness of the sheet *t* is variable. We solve for this parameter Eq. (6) and introduce the result into Eq. (5), thus obtaining:

$$M \le \left(\frac{5FL^6b^2}{32\delta}\right)^{1/3} \frac{1}{\left(\frac{E^{1/3}}{\rho}\right)} \qquad (7)$$

The optimum material for our application – *i.e.* the one that weighs the least, with the rigidity constraint expressed by its deflection – is the one with the highest value of the K_1 index :

$$K_1 = \frac{E^{1/3}}{\rho} \qquad (8)$$

In our case, the values of *E* and ρ to be used are those of steel given in Table I.

Design for plastic deformation

The goal of materials selection consists in choosing from among the proposed candidate materials the most suitable one to manufacture: in this particular case, metal sheets of length *L*, variable width *b* and thickness *t* that possesses the minimum weight at the same time as presenting the maximum resistance to plastic deformation.

Applying Navier's Law [35] also referred in literature as the flexion formula, to the axial stress in a beam, we have:

$$\frac{\sigma}{\Gamma} = \frac{y}{I} \qquad (9)$$

and in the case of maximum stress:

$$\sigma_{max} = \frac{\Gamma_{max} \times y_{max}}{I} \qquad (10)$$

where Γ_{max} is the maximum deflective moment in a section between the central section and one of the supports. As shown in the previous Section, the maximum moment for this setup is obtained for $x = L/2$, and takes the value of $\Gamma_{max} = \frac{FL}{8}$. Further, y_{max} is the distance to the neutral line (corresponding to half the thickness), so that $y_{max} = t/2$. The moment of inertia I is calculated from the thickness using Eq. (3). We thus obtain:

$$\sigma_{max} = \frac{3}{4}\frac{FL}{bt^2} \qquad (11)$$

Bearing in mind that the mass expression is given by Eq. (5) and that we are seeking the material that possesses the maximum resistance to plastic deformation, the following condition must be fulfilled:

$$\sigma_{max} \le \sigma_y \qquad (12)$$

Substituting the value corresponding to the working stress, we obtain:

$$\frac{3}{4}\frac{FL}{bt^2} \le \sigma_y \qquad (13)$$

which allows us to obtain the value of the variable term for the thickness t:

$$t \ge \left(\frac{3FL}{4b\sigma_y}\right)^{1/2} \qquad (14)$$

Substituting in turn this result into the mass equation and separating the fixed term from the variable term, we obtain

$$M \ge \left(\frac{3FL^3b}{4}\right)^{1/2} \times \frac{1}{\left(\frac{\sigma_y^{1/2}}{\rho}\right)} \qquad (15)$$

The above result tells us that - in order to minimize the weight and simultaneously avoid the risk of plastic deformation - the following term must be maximized:

$$K_2 = \frac{\sigma_y^{1/2}}{\rho} \qquad (16)$$

Design for the risk of unstable failure

Unstable failure takes place when the material contains cracks exceeding a critical size for the nominal stress σ obtained for the beam subject to bending [36 - 40]. By application of Navier's Law in Eq. (11) and using the Griffith equation:

$$K_{IC} \ge Y \cdot \sigma \cdot \sqrt{\pi a} = Y \cdot \frac{3FL}{4bt^2} \cdot \sqrt{\pi a} \qquad (17)$$

where Y is a dimensionless parameter that depends on both the specimen and crack geometries.

Solving for the variable t in Eq. (17) and substituting this value into the mass equation, we obtain:

$$M \le \left[C \cdot \left(FL^3 b\right)^{1/2} \cdot a^{1/4}\right] \times \frac{1}{\left(\frac{K_{IC}^{1/2}}{\rho}\right)} \qquad (18)$$

The simple mass merit index K_3, which is to be maximized and which allows us to determine the lightest material with the minimum risk of unstable failure, is given by:

$$K_3 = \frac{K_{IC}^{1/2}}{\rho} \qquad (19)$$

Despite the fact that the goal of obtaining merit indexes is none other than that of choosing from among a series of candidate materials the one that optimizes the desired physical and mechanical properties for a given application, we recall that the starting material in this study is steel.

3. ANALYSIS

A comparison was made between models of the same make under the hypotheses of different mileages until the end of the vehicle's service life (scrap yard). Thus, the possibility of a low mileage is evaluated –which would be the case of Northern Europe and USA – and three times this mileage – which might be the case in other instances: third world countries, countries with extensive second-hand vehicle providers, etc. In this comparison, sedan vehicles and their off-road equivalents were always considered with the aim of deciding – on the basis of one component, the bonnet – the increase in energy costs that a change in the choice of the purchased vehicle would result when considering the former as opposed to the latter version. The result of this analysis leads us to question the use of off-road vehicles on paved roads, given that an increase in energy costs is produced with respect to their sedan equivalents in all cases. Energy consumption is included in the first of the indexes considered in this study, *i.e.* the LEC (Lifetime Energy Consumption), which takes into consideration the previously calculated mass merit indexes in its formulation.

The most novel contribution of this study on materials selection is the inclusion of the GHE (Greenhouse Effect) parameter, based on one of the five gases that contribute to this effect, namely CO_2 from fossil fuels, mainly produced during the service of the automobile.

A. LEC Index

In what follows, the LEC index is derived; it represents the energy consumption resulting from the use of the automobile during its service life. The aim is to establish the portion of the energy consumption associated with manufacturing (LEC-1) and that due to use of the vehicle (LEC-2), the LEC index being the sum of the two. For the latter of the individual terms, we now show the calculations needed to obtain an index, which we shall call c_S, for an estimated vehicle service life of 100,000 and 300,000 kilometres in the case of the several car models.

The aim is thus to establish the portion, for a service life estimated in terms of mileage, of the increase in energy consumption versus the increase in that parameter under the assumption of using an off-road vehicle compared to its sedan equivalent. The procedures for calculating the values of c_S shown in Table III are shown next in this section.

Table III. LEC index expression in terms of the several mechanical properties that need to be minimized

On the basis of:	LEC-1 (*Manufacturing*)	LEC-2 (*Service life*)	LEC (*Total*)
Rigidity	$\text{LEC-1} = \left(\frac{\rho \cdot q}{E^{1/3}}\right)$	$\text{LEC-2} = \left(\frac{\rho \cdot c_S}{E^{1/3}}\right)$	$\text{LEC} = \left(\frac{\rho . q}{E^{1/3}}\right) + \left(\frac{\rho . c_S}{E^{1/3}}\right)$
Resistance to plastic deformation	$\text{LEC-1} = \left(\frac{\rho \cdot q}{\sigma_y^{1/2}}\right)$	$\text{LEC-2} = \left(\frac{\rho \cdot c_S}{\sigma_y^{1/2}}\right)$	$\text{LEC} = \left(\frac{\rho . q}{\sigma_y^{1/2}}\right) + \left(\frac{\rho . c_S}{\sigma_y^{1/2}}\right)$
Risk of unstable failure	$\text{LEC-1} = \left(\frac{\rho \cdot q}{K_{IC}^{1/2}}\right)$	$\text{LEC-2} = \left(\frac{\rho \cdot c_S}{K_{IC}^{1/2}}\right)$	$\text{LEC} = \left(\frac{\rho . q}{K_{IC}^{1/2}}\right) + \left(\frac{\rho . c_S}{K_{IC}^{1/2}}\right)$

All fuels can be described in terms of their energy per unit of mass. In this paper, we shall express the energy content of fuels in megaJoules per litre (MJ/l). In our calculations the Calorific Power of the fuel was assumed to take the value of 38.5 MJ/litre-diesel for Diesel engines and of 32 MJ/litre-gasoline for gasoline engines - values obtained from the data provided by the Oak Ridge National Laboratory [38].

The value of c_S for one of the models in the case of a service life of 100,000 kilometres (which would be the case of the USA and northern European countries where new vehicles are usually replaced after a low mileage) was determined as follows:

In the case of the car identified in Table II as Diesel 3 off-road, with the weight of 2,185 kg, the energy consumption during covering that distance is:

$$100{,}000\ \text{km} \times \frac{9.8\,\text{l}}{100\,\text{km}} \times 38.5\frac{\text{MJ}}{\text{l}} = 377{,}300\ \text{MJ} \tag{20}$$

For the equivalent sedan with the weight 1,815 kg:

$$100{,}000\ \text{km} \times \frac{7.9\,\text{l}}{100\,\text{km}} \times 38.5\frac{\text{MJ}}{\text{l}} = 304{,}150\ \text{MJ} \tag{21}$$

Combining Eqs. (20) and (21), we obtain the c_S value for that vehicle with an expected lifespan of 100,000 kilometres:

$$c_S = \frac{\Delta\text{Energy}}{\Delta\text{Mass}} = \frac{377300 - 304150}{2185 - 1815} = 197.70\frac{\text{MJ}}{\text{kg}} \tag{22}$$

This means an increase in consumption of approximately 198 MJ/kg when driving the off-road model, an increase that refers to a service life of only 100,000 kilometres. This result highlights low usefulness of buying an off-road vehicle to be driven on paved roads.

We now present similar calculations carried out to determine the c_S value but assuming a service life of 300,000 kilometres. We have used a correction factor of 1.15 (~15% increase), based upon the authors experience, since consumption rises progressively as the number of kilometres that the vehicle has been driven increases (increased slack in the engine, etc.) as a consequence of the mechanical wear it suffers. In other words, MPG will go down as parts wear and reduce efficiency. Some are inexpensive and easy to replace, like spark plugs, sensors and thermostats, which will take consumption back to a low value. However major mechanical parts like rings and valve seats when worn reduce compression and increase fuel consumption. These are expensive to replace, so it makes more economic sense to live with their gradual degradation, and thus with an increase in fuel consumption.

For the same off-road diesel model chosen before (Diesel 3 off-road):

$$300{,}000\,\text{km} \times \frac{9.8\,\text{l}}{100\,\text{km}} \times \underbrace{1.15}_{\substack{\text{ageing}\\ \text{factor}}} \times 38.5\frac{\text{MJ}}{\text{l}} = 1{,}301{,}685\,\text{MJ} \tag{23}$$

While the equivalent sedan model (Diesel-3 sedan):

$$300{,}000\,\text{km} \times \frac{7.9\text{l}}{100\,\text{km}} \times \underbrace{1.15}_{\substack{\text{ageing}\\ \text{factor}}} \times 38.5\frac{\text{MJ}}{\text{l}} = 1{,}049{,}317\ \text{MJ} \tag{24}$$

Combining Eqs. (23) and (24), we obtain the new value of c_S for the two vehicles with an expected lifespan of 300,000 kilometres:

$$c_S = \frac{\Delta\text{Energy}}{\Delta\text{Mass}} = \frac{1{,}301{,}685 - 1{,}049{,}317}{2{,}185 - 1{,}815} = 682.07\frac{\text{MJ}}{\text{kg}} \tag{25}$$

From the calculation of the c_S index, which we call the specific energy consumption, it can be appreciated that when the vehicle has been driven 300,000 km instead of 100,000 km, the difference in energy consumed due to having chosen the off-road versus the sedan model implies the exchange constant 3.45 times higher.

We have provided above just an example. Results of such calculations are summarized in Figure 5. We see in that Figure that a growing trend in the specific fuel consumption can be appreciated in all the makes. The effect is the smallest for the hybrid car.

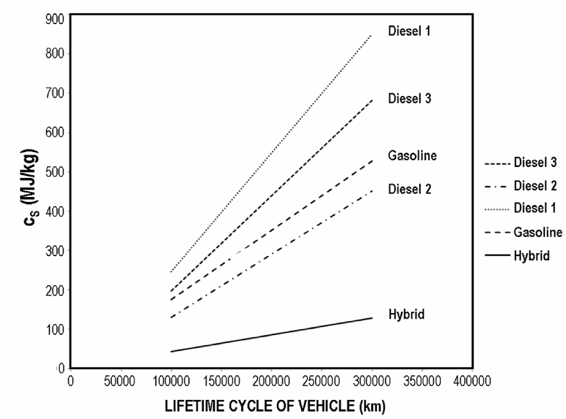

Figure 5. Evolution of the coefficient c_S versus the estimated service life of the vehicle.

Our analysis should be carefully interpreted since we are referring here to specific consumptions, *i.e.* consumption normalized to the total mass of each vehicle. The latter only considers the energy efficiency of the vehicle and its type of engine. It should be borne in mind that the consumed energy depends on the fuel consumption (Table II) as provided by the manufacturer (Fig. 6). If we consider non-specific consumption, the heavy weight hybrid sedan car becomes comparable to other cars, diesel or gasoline. The hybrid off-road car selected in this study despite being the heaviest among off-road cars in Table II, seems the right choice from the standpoint of view of its lowest mixed fuel consumption.

The next step consists in calculating the LEC-1 and LEC-2 indexes, the sum of which gives the LEC index. We shall use different criteria to analyse the two indexes, taking into account the specific mechanical properties of the material, which will also include the energy content and specific consumption. Formulae for calculation of these indexes are given in Table III. As an example, we show now the derivation of index LEC-2 for the case of resistance to plastic deformation. Assuming the total specific energy consumption c_T to depend both on the mass of the vehicle (or the mass of a given component), and on the proportionality factor c_S:

$$c_T = M \cdot c_s \qquad (26)$$

Combining Eqs. (15) and (26):

$$c_T \geq \left(\frac{3FL^3 b}{4}\right)^{1/2} \times \underbrace{\left(\frac{\rho \cdot c_S}{\sigma_y^{1/2}}\right)}_{\text{LEC-2 (yielding)}} \qquad (27)$$

LEC-2 in Eq. (27) corresponds to a sheet of metal with enough resistance to yielding and low specific fuel consumption c_S. It is the

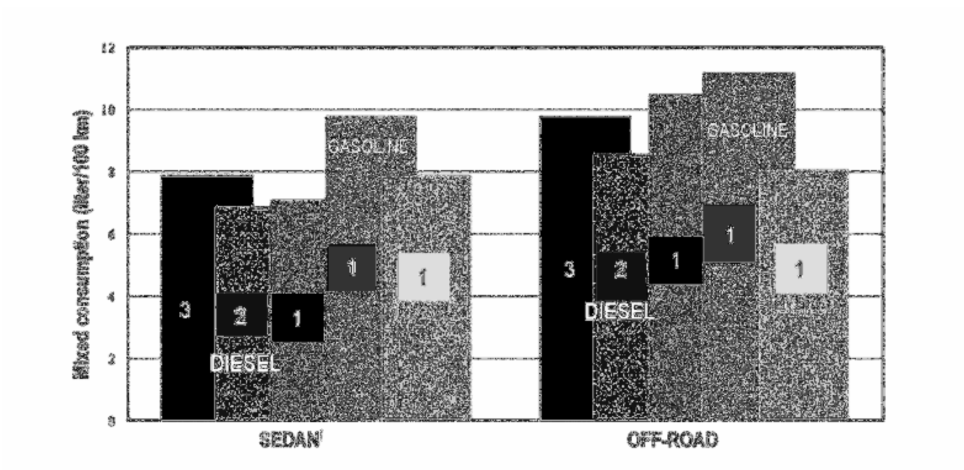

Figure 6. Mixed consumption in the different vehicles.

Table IV. LEC index at 100,000 km for a bonnet made of HSLA steel

LEC index on the basis of:	DIESEL 1	DIESEL 2	DIESEL 3	GASOLINE	HYBRID
Rigidity	$3.483 \cdot 10^5$	$2.601 \cdot 10^5$	$4.124 \cdot 10^5$	$3.192 \cdot 10^5$	$1.435 \cdot 10^5$
Resistance to plastic deformation	$8.451 \cdot 10^4$	$6.310 \cdot 10^4$	$1.001 \cdot 10^5$	$7.745 \cdot 10^4$	$3.482 \cdot 10^4$
Risk of unstable failure	$1.974 \cdot 10^5$	$1.474 \cdot 10^5$	$2.337 \cdot 10^5$	$1.809 \cdot 10^5$	$8.133 \cdot 10^4$

Table V. LEC index at 300,000 km for a bonnet made of HSLA steel

LEC index on the basis of:	DIESEL 1	DIESEL 2	DIESEL 3	GASOLINE	HYBRID
Rigidity	$9.879 \cdot 10^5$	$6.835 \cdot 10^5$	$1.209 \cdot 10^6$	$1.209 \cdot 10^6$	$2.306 \cdot 10^5$
Resistance to plastic deformation	$2.397 \cdot 10^5$	$1.658 \cdot 10^5$	$2.934 \cdot 10^5$	$1.901 \cdot 10^5$	$6.217 \cdot 10^4$
Risk of unstable failure	$5.599 \cdot 10^5$	$3.874 \cdot 10^5$	$6.853 \cdot 10^5$	$4.439 \cdot 10^5$	$1.452 \cdot 10^5$

second term in the product in the above inequality and it is often called materials' term. It should be minimized so as to keep the total consumption c_T low.

Regardless of the mechanical property we consider, the aim is to minimize the LEC index. This means minimizing the energy content and the specific consumption while maximizing the mechanical property addressed in each case. Calculating this index, substituting the properties of the steel and the specific consumptions calculated in the corresponding expressions in Table III for the two mileages considered, we obtain the values shown in Tables IV and V. The aim here is to find the vehicle that presents a lower value when changing between the sedan and the off-road model both at 100,000 km and 300,000 km.

We find that all the makes present very similar values when the mileage is 300,000 km, except for the hybrid vehicles.

B. GHE Index

CO_2 is inherent to all combustion processes, being one of the causes of the greenhouse effect and jointly responsible for global warming of the atmosphere. In Western Europe, two thirds of total emissions of the six gases contemplated in the Kyoto Protocol correspond to CO_2 emissions coming from energy sources. In 2005, transport was responsible for 30 % of CO_2 emissions. The actual level of CO_2 emissions depends on the performance of the vehicle and its use (speed and frequent changes in speed, driving in low gears, etc.) [42].

Emissions of this gas are reduced significantly by consuming less fuel, *i.e.* driving at low speeds without accelerating brusquely and therefore increasing energy efficiency in trips. Many cars now incorporate arrows in the dashboard of manual gear-change models that light up, suggesting that the driver should go up or down a gear so as to drive in an environmentally friendly way.

Gasoline and diesel engine sedans are predominant in Europe. The most important differences between these vehicles reside in the way the fuel is mixed with air and the way in which combustion occurs in the engine. Some countries like Sweden and the USA have developed car models to work with variable proportions of gasoline and bioethanol. Although the most hazardous emissions from gasoline are significantly reduced, fuel consumption increases when using bioethanol rather than gasoline, due to the lower energy content per unit volume of ethanol with respect to unblended gasoline [43].

We are witnessing and shall continue to witness significant changes in both diesel and gasoline engines. Actually, neither of the two types of engines is better or worse than the other; they simply have their own features that make them function differently. From the perspective of fuel savings in these types of engines, some of the aforementioned changes consist in incorporating Start/Stop and Auto Start/Stop technologies in both diesel and gasoline engines. These technologies consist in a simple mechanism that stops the engine when the car stops and has no gear engaged, which helps in reducing gas emissions, noise and fuel consumption to zero if most of the driving takes place in cities. Other car maker trends with respect to manufacturing more environmentally friendly cars have focused on modifying engine management towards lower consumption (work with leaner mixes of fuel and air, recirculation of the exhaust gases into the combustion chamber, etc.), improving aerodynamic behavior (mainly by reducing chassis height) and the use of lower friction tires.

A somewhat radical change came with hybrid cars, which probably represent the most environmentally friendly vehicles available on the car market at a commercial scale. Their technology consists in combining a gasoline engine with an electrical motor, which apart from improving their mechanical performance is also environmentally friendly. The existing models on the market consume very little gasoline and have very low CO_2 emissions. They also offer the possibility of moving over a short distance using only the electric motor so as to reduce emissions and noise to zero in certain areas (semi-pedestrian roads, in the vicinity of schools and hospitals, the city center, etc.). Some of the most realistic forecasts made by specialists in the automotive sector, stress that gasoline hybrid vehicles are the bridge between today's conventional vehicles, and future diesel hybrid [39] and plug-in hybrid [40] cars.

We now define e_S as the increase in CO_2 emissions for a service life estimated in terms of mileage, referred to the increase in weight between an off-road model and its equivalent sedan of the same make. We also refer to it as the exchange specific emission coefficient, which we represent in an analogous way to the term c_S:

$$e_S = \frac{\Delta \text{Emissions}}{\Delta \text{Mass}} \tag{28}$$

Once the value of e_S has been calculated, we can calculate the Greenhouse Effect (GHE) - the index that allows us to quantify the effect of the candidate materials on the environment while optimizing a structural property and minimizing its mass. We shall then use the same structural properties for this study as we did for the LEC index.

We now show the necessary calculations to obtain the e_S index at 100,000 and 300,000 kilometres in the case of the same car model with a hybrid engine. The procedure for calculating the values of e_s for the remaining makes will be identical; it will only be necessary to substitute the values with those of the corresponding make and model.

In the case of the off-road hybrid vehicle (2,505 kg) we have:

$$100{,}000\,\text{km} \times \frac{192\text{g CO}_2}{\text{km}} \times \frac{1\text{Ton}}{10^6\,\text{g}} = 19.2\ \text{Ton CO}_2 \tag{29}$$

For the corresponding sedan model (2,365 kg) we have:

$$100{,}000\,\text{km} \times \frac{185\text{g CO}_2}{\text{km}} \times \frac{1\text{Ton}}{10^6\,\text{g}} = 18.5\,\text{Ton CO}_2 \tag{30}$$

Combining Eqs. (28) and (29), we obtain the GHE value for the hybrid vehicles with an expected lifespan of 100,000 km:

$$e_S = \frac{\Delta\text{Emissions}}{\Delta\text{Mass}} = \frac{19.2 - 18.5}{2505 - 2365} = 5 \times 10^{-3}\,\frac{\text{Ton CO}_2}{\text{kg}} \approx 5\,\frac{\text{kg CO}_2}{\text{kg}} \tag{31}$$

We next show the necessary calculations to obtain the value of e_s in the case of the same models, though now with an "expected life" of 300,000 kilometres. As in the calculation of the value of c_S at 300,000 kilometres, an aging correction factor equal to 1.15 has been applied here.

For the hybrid off-road model (2,505 kg) we have:

$$300{,}000\,\text{km} \times \frac{192\text{g CO}_2}{\text{km}} \times \frac{1\text{Ton}}{10^6\,\text{g}} \times \underbrace{1.15}_{\substack{\text{ageing}\\\text{factor}}} = 66.24\,\text{Ton CO}_2 \tag{32}$$

while for the corresponding sedan vehicle (2,365 kg) we get:

$$300{,}000\,\text{km} \times \frac{185\text{g CO}_2}{\text{km}} \times \frac{1\text{Ton}}{10^6\,\text{g}} \times \underbrace{1.15}_{\substack{\text{ageing}\\\text{factor}}} = 63.82\,\text{Ton CO}_2 \tag{33}$$

Combining Eqs. (31) and (32), we obtain the e_s value for hybrid vehicles with an expected life of 300,000 km:

$$e_S = \frac{\Delta\text{Emissions}}{\Delta\text{Mass}} = \frac{66.24 - 63.82}{2505 - 2365} = 1.728 \times 10^{-2}\,\frac{\text{Ton CO}_2}{\text{kg}} \approx 17.28\,\frac{\text{kg CO}_2}{\text{kg}} \tag{34}$$

Table VI shows the differences in specific emissions between a sedan model and its off-road equivalent for the two mileages considered.

Table VI. Values of $\boldsymbol{e}_S$ versus the considered service life

NAME	**e_S** [kg CO_2/kg] 100,000 km	300,000 km
DIESEL 1	13	44.8
DIESEL 2	9	31.1
DIESEL 3	17.5	60.5
GASOLINE	12.5	43.3
HYBRID	4.7	17.3

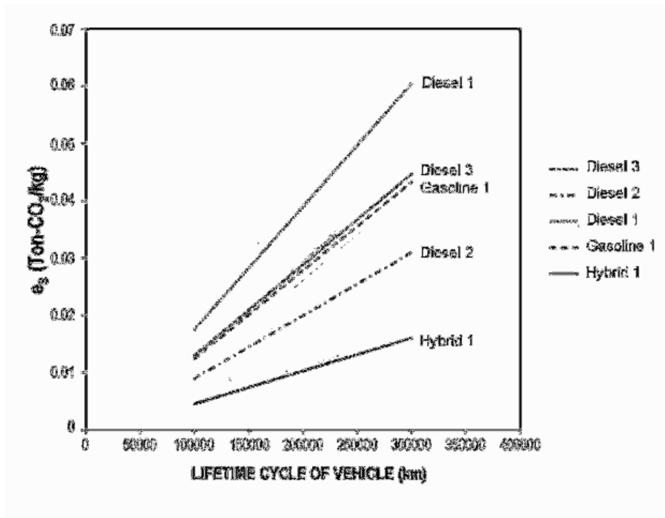

Figure 7. Evolution of the coefficient e_S versus the estimated service life of the vehicle.

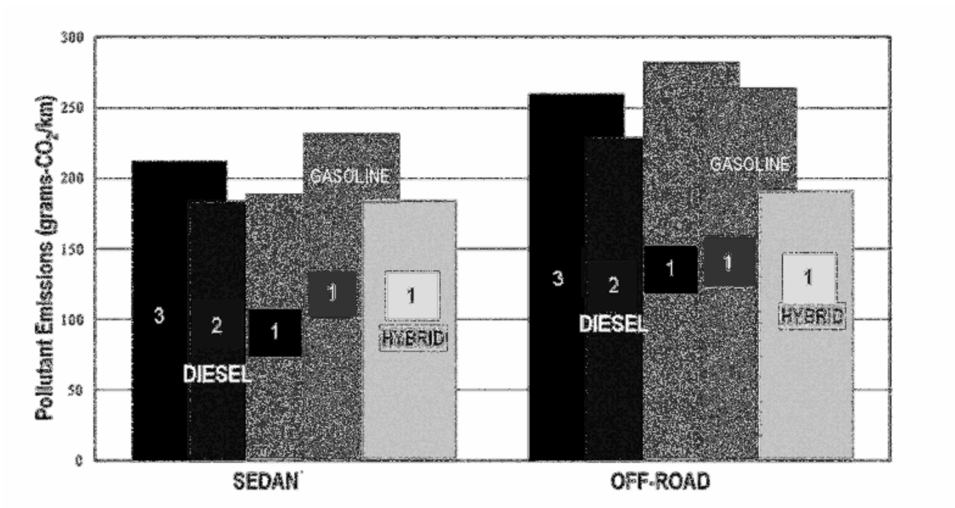

Figure 8. Total CO_2 emissions per km for the different vehicles studied.

A growing trend in specific CO_2 emissions can be appreciated in Figure 7 - corresponding to Table VI. Again, caution is advised when interpreting these results since we are looking at specific emissions per 1 kg of the vehicle. It can be inferred that hybrid cars exhibit the lowest emission coefficient e_S, indicating that the amount of CO_2 emitted per unit mass are the best at any distance covered by these models. We find them to be the most efficient cars. If instead we consider the vehicle total CO_2 emissions (pertaining to all of its mass), the hybrid cars are less pollutant; see Figure 8 and Table II. Further, we conclude that both the specific and total CO_2 emissions are in agreement. It seems reasonable that the contribution of the electric motor designed to assist the gasoline engine in hybrid cars is responsible for the low amounts of the total CO_2 released by the studied models, an achievement reached without penalizing the total car power.

With all the calculated e_S values, we may now attempt to evaluate the effect on the environment of the candidate materials for the manufacture of the vehicle bonnet - in terms of the contribution to the greenhouse effect (GHE) due to CO_2 emissions.

The next step consists in calculating the GHE index, taking into account the specific mechanical properties of the material as developed in the previous LEC index, now including the specific emission coefficient e_S. Formulae for these indexes are provided in Table VII.

Regardless of the mechanical property we begin with, the aim always is to minimize the indexes discussed above. This is equivalent to minimizing the specific emissions while maximizing the mechanical property under consideration. Substituting the properties of the steel and the specific emissions calculated in the corresponding expressions in Table VII for the two mileages under consideration, we obtain the values presented in Tables VIII and IX. The differences between the sedan and off-road models for 100,000 km and 300,000 km can once more be appreciated.

In view of the results obtained for the GHE index, in this particular case for a bonnet of variable thickness made from HSLA steel, and considering the mechanical properties analyzed, we conclude that irrespective of the mileage covered the order quality of cars studied can be formulated. Such calculations should not mislead the reader into judging which car is better. We have actually only considered one single car component and not the whole car. Nevertheless, we consider this methodology to be a powerful tool in the student learning process.

4. A SURVEY OF CONCLUSIONS

The present study comprises the development of a method for selecting capital goods that are environmentally friendly in terms of available energy resources.

Table VII**.** Green House Effect Index (GHE) expressions in terms of the different specific mechanical properties considered in this study

On the basis of:	GHE
Rigidity	$\frac{\rho \cdot e_S}{E^{1/3}}$
Resistance to plastic deformation	$\frac{\rho \cdot e_S}{\sigma_y^{1/2}}$
Risk of unstable failure	$\frac{\rho \cdot e_S}{K_{IC}^{1/2}}$

Table VIII. GHE index at 100,000 km for a car bonnet made of HSLA steel

GHE index on the basis of:	DIESEL 1	DIESEL 2	DIESEL 3	GASOLINE	HYBRID
Rigidity	17.13	11.89	23.17	16.57	6.16
Resistance to plastic deformation	4.16	2.88	5.62	4.02	1.50
Risk of unstable failure	9.71	6.74	13.13	9.39	3.49

Table IX. GHE index at 300,000 Km of the considered makes for a car bonnet made of HSLA steel

GHE index on the basis of:	DIESEL 1	DIESEL 2	DIESEL 3	GASOLINE	HYBRID
Rigidity	59.11	41.01	79.95	57.18	21.26
Resistance to plastic deformation	14.34	9.95	19.40	13.88	5.18
Risk of unstable failure	33.50	23.24	45.31	32.40	12.05

Taking the reference of a steel bonnet, as a common component in a variety of automobiles and one which has certain expected mechanical properties, simple indexes are first derived for the requirement of minimum total weight. Subsequently, taking into consideration energy and environmental criteria and considering several car models, complex indexes are derived based on the earlier simpler indexes. This enables us to discern the most rational environmentally-friendly choice on the basis of the intended mileage throughout the service life of the vehicle. The method likewise allows the rationalization of the most environmentally friendly choice of off-road vehicles versus their sedan equivalents. In particular, the following conclusions may be highlighted:

In terms of weight-standardized indexes, it is seen that a hybrid-gasoline engine system achieves similar fuel consumptions to that of the best diesel vehicles due to the fact that the former (tandem) system aims to compensate, on the one hand, the lower energy content per litre of gasoline and, on the other, the poorer performance of the Otto cycle versus the Diesel cycle.

As to the type of model chosen within one and the same make, it has been shown that regardless of the make, the change from a sedan to an off-road model provides negative results in environmental terms.

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ADDING DETAILED STUDENT-LEARNING OBJECTIVES, GROUP LEARNING, AND ASSESSMENTS TO AN INTRODUCTORY PLASTICS ENGINEERING COURSE

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ABSTRACT

“Materials and Processes in the Plastics Industry” is a three credit-hour course at Northern Illinois University within the Department of Technology. Is an introductory course in plastics technology designed to familiarize the student with the basic plastics/polymers. The course has been reorganized to focus the learning process around the student and specific student-learning objectives and outcomes connected to curriculum topics and various types of learning assessments. Higher-level objectives that stress designing, planning, judging, and analyzing are emphasized. Teaching is partially shifted to group learning and techniques are suggested to maximize the individual’s performance in a group setting. Scoring rubrics are part of the assessment system. Traditional examination questions are retained but now each question is connected to a specific student-learning objective. Examples of learning objectives, syllabus content, a performance task, assessment rubric, and examination questions are presented for this, or any, introductory plastics course. The focus of this discussion is the preparation of such reorganization, as the course has not yet been implemented in this newer format. Future data from several offerings of this course should be analyzed and utilized to make continuous improvements.

Keywords: *assessment; group learning; plastics technology; student-learning objective*

BACKGROUND

At Northern Illinois University (NIU), an introductory plastics course is offered within the Department of Technology. This three credit-hour course (TECH 344) is titled “Materials and Processes in the Plastics Industry.” The Department of Technology is part of the College of Engineering and Engineering Technology along with the Departments of Electrical, Industrial, and Mechanical Engineering. The Department of Technology is comprised of three undergraduate emphases: Manufacturing Engineering Technology, Electrical Engineering Technology, and Industrial Technology. Specifically for the Industrial Technology students, there are four areas of study: Computer-Aided Design, Manufacturing Technology, Occupational Safety, and Plastics. TECH 344 fulfills one of the Plastics required classes and is an elective for Computer-Aided Design, Manufacturing Technology, and Mechanical Engineering undergraduates. Industrial Technology received initial accreditation in 1998 from the National Association of Industrial Technologists (NAIT) – now Association of Technology, Management, and Applied Engineering (ATMAE).

"Materials and Processes in the Plastics Industry" familiarizes the student with the basic plastics/polymers along with some plastics fabrication processes. Topics include:

- History of Plastics;
- Basic Concepts in Organic Chemistry;
- Materials: Thermoplastics, Thermosets, and Elastomers;
- Properties;
- Additives, Fillers, and Reinforcements;
- Fabricating with Plastics;
- Recycling, Environmental Aspects; and
- Plastics Processing Methods.

There is no formal laboratory although there are demonstrations, in the laboratory, of some of the common plastics processing methods. (Plastics processing is extensively studied in another course, TECH 345.) Each student has the opportunity to learn the origin, the identity, and the characteristics of the major plastics along with current process terminology and product applications. The course is similar to introductory polymer science or polymeric materials courses elsewhere in chemical engineering, materials science, and mechanical engineering or technology departments although the emphasis in TECH 344 is more on the properties and application of plastics rather than the chemistry. For example, the basic addition and condensation reactions forming polymers are included in the curriculum, but details of reaction rates and the initiation, propagation, and termination steps are not. Typically, students meet twice a week for 75-minute sessions during a 16-week semester with the last week reserved for final examinations. Historically, students in TECH 344 are exposed to an instructor-centered command style[1] program where the instructor makes all the decisions and determines what is taught and how it is evaluated. A command style is potentially less effective in a plastics course as it has been observed that students routinely carry misconceptions concerning fundamentals and properties of materials[2]. Thus, even the initial, basic terminology used by the instructor – matter, molecules, density, phases – is not understood by students and leads to problems comprehending more advanced polymer topics.

Currently, in an effort to improve student instruction, performance, and retention, TECH 344 has been reorganized. Although the full revision of the course has not yet been implemented, the focus here is its setup. Now the approach to learning is constructed around student-learning objectives and outcomes connected to specific curriculum topics and various types of learning assessments. Multiple teaching and learning models have been incorporated with higher-level objectives of Bloom's Taxonomy[3] that stress designing, planning, judging, and analyzing rather than traditional recalling, classifying, summarizing, or naming. The reorganization of TECH 344 required revising the course content, syllabus, examinations, lectures, and projects.

STUDENT-LEARNING OBJECTIVES

The first step in the reorganization process was the identification of each pertinent student-learning objective (SLO) to ensure that course topics reinforce the objectives. The curriculum was adjusted to reflect all these changes. In the next step, various teaching and learning models were incorporated to shift the program from instructor-centered to more student-centered where individually, or in groups, students take responsibility for the learning process. Finally, student assessments were developed to judge how well objectives are attained. This required analysis of previous course examinations, revision of these examinations, and development of new performance tasks that provide alternative assessments of the same knowledge.

Rubrics were constructed to evaluate the performance tasks.

Two sets of learning objectives are present: general engineering ATMAE objectives and course-specific ones. For instance, an ATMAE learning outcome, or objective is to:

> ***Apply current knowledge and adapt to emerging application of math, science, engineering, and technology.***

To achieve this outcome, TECH 344 includes the SLOs and sub-objectives of:

A. Students will Describe the Fundamental Structure of Plastics:

A.1. Students will interpret and draw polymer chains.
- A.1.a. Students will compare and contrast polymerization reactions.
- A.1.b. Students will compare and contrast functional groups and tacticity.
- A.1.c. Students will describe chain topology.

A.2. Students will compare and contrast thermoplastics and thermosets.
- A.2.a. Students will select commodity and engineered plastics.
- A.2.b. Students will ascertain specific differences between crystalline and amorphous plastics.

A.3. Students will name, draw, and identify elastomers.
- A.3.a. Students will explain elastomers.
- A.3.b. Students will outline structure and polymerization of polyisoprene.
- A.3.c. Students will outline structures of other elastomers.

B. Students will Predict Plastics Properties:

B.1. Students will describe effects of structural features on plastics properties.
- B.1.a. Students will quantify and solve molecular weight and molecular weight distribution problems.
- B.1.b. Students will qualitatively evaluate crystallinity effects.

B.2. Students will identify the mechanical, physical, thermal, environmental, electrical, and optical properties most relevant to the design of plastic products.
- B.2.a. Students will select appropriate ASTM standards to characterize those properties.

B.3. Students will explain variation of properties of plastic products by the use of modifiers.
- B.3.a. Students will classify additives, fillers, and reinforcements.

C. Students will Describe Plastics Design and Finishing Processing:

C.1. Students will compare in detail industrial design methods.

C.2. Students will survey shaping and post-molding methods for plastic products.
- C.2.a. Students will select machining methods.

C.3. Students will explain methods of finishing plastics.
- C.3.a. Students will give examples of joining and decorating.

D. Students will Recognize the Environmental Aspects of Plastics:

D.1. Students will explain waste reduction techniques.
- D.1.a. Students will evaluate source control, recycling, regeneration, degradation, landfills, and incineration.

E. Students will Analyze, in Depth, a Specific Plastics Topic:

E.1. Students will construct the history of a plastics topic, or

E.2. Students will report on structure, production, and applications of a plastic, or

E.3. Students will detail a plastics processing method, or

E.4. Students will describe, in great technical detail, a plastic product.

Appropriate textbook and lecture materials were selected to meet these objectives and the syllabus recorded the order and progress of meeting objectives and outcomes.

GROUP-LEARNING-ORIENTED SYLLABUS

A syllabus was planned that placed some of the burden of learning on the students. It combined instructor-centered instruction followed by student-centered group learning. As an example, part of student-learning outcome A. is:

A.2. Students will compare and contrast thermoplastics and thermosets.
A.2.a. Students will select commodity and engineered plastics.

while the corresponding syllabus entries are:

Week and Objectives	Day 1 Topics, Activities, and Due Dates	Day 2 Topics, Activities, and Due Dates
Week #6 Select Thermosets. Note Differences between Features and Qualities of Commodity and Engineered Thermoset Plastics.	Commodity Thermosets.	Engineered Thermosets. Read Chapter 9 of Textbook* due 10/11. Group: Students Sum Up Engineered Thermosets due 10/11. Homework: Chapter 9 Questions (evens) due 10/13. * A. B. Strong, *Plastics: Materials and Processes*, Pearson Education, Inc., Upper Saddle River, NJ, 2006.
Week #7 Name, Draw, and Label Elastomers.	Polyisoprene. Group: Students Discuss and Outline Structure and Polymerization of Polyisoprene due 10/13.	Other Elastomers. Performance Task 2 due 11/8. Homework: Chapter 10 Questions (evens) due 10/20.

These two weeks represent four class periods. In the first, day 1 of week 6, the focus is on instruction by lecture with the topic being commodity (common) thermosetting resins. However, day 2 of week 6 represents a shift as students in groups, following the formatted examples from the instructor's lectures, construct their own set of lecture notes for engineered thermosetting resins. A due date for this assignment is given along with an individual homework assignment to further reinforce the material by presenting the same information from a different source to take advantage of various learning styles among students. (A similar approach is used in prior weeks for thermoplastics.) Note that the syllabus is essentially a collection of weekly subjects that can be taught in modules, especially when each module is centered on a topic popular with students. Recent engineering course development indicated a favorable 69% of students reporting learning more when polymers were combined with a sports-oriented module, and 39% claimed more course satisfaction compared with other, traditional courses[4]. Along the same lines, Wang *et al.*[5] propose that in addition to using a topic that students are familiar with and interested in - such as sports – learning is enhanced when a polymer achievement is in the form of a story; this could be the research and product improvement leading to a specific piece of sports equipment. Their study also suggests incorporating any of the instructor's research findings that relate to the topic as a third element to reinforce the popular topic choice and its story.

In this regard, it is vital that any groups are legitimate cooperative learning groups where students are randomly assigned and outperform reasonable expectations by their combined efforts. Additionally, each individual in the group must be independently evaluated. Examples to accomplish this include keeping the group size small, giving written or oral examinations to students, and observing students as they interact within their group.

There are systematic techniques available to maximize the individual's performance in a group setting[6]. These techniques cover various ways of forming groups, including ensuring that the groups are random and/or balanced. Different ways of group functioning and dynamic interaction are also documented. A sampling includes rounds where students take turns speaking; group investigation where each group is free to choose a subtopic within the area of study; discussions where students take opposing sides of an issue; and brainstorming to encourage freethinking and rapid development of ideas.

In any case, the vital elements of group learning are to assign personal responsibility to each student along with individual accountability. A group must actually engage in learning, not just doing a task or assignment; this requires the group to produce a product at the end of the session and the product must be assessed against very specific criteria. In the end, each student will perform at a level above their individual capability, benefiting from the group-learning process.

For TECH 344, the proposed evaluation tool is to select homework assignments which are to be prepared in class. For each of these assignments, half the groups will be selected randomly and those students will complete the assignment individually, without the benefit of the group. For the next assignment, the process is reversed with the individual back within the group to execute the homework. The performance of each student, acting individually and within the group-learning environment, will be measured to evaluate the effectiveness of cooperative learning groups.

Week 7 continues the process for elastomers. Furthermore, week 7 contains an additional assignment labeled Performance Task 2, which provides another way for students to fulfill their learning objective of being able to understand specific polymers, and addresses student-learning objective E: Students will Analyze, in Depth, a Specific Plastics Topic. Performance Task 2 is also described in the TECH 344 syllabus:

> *You are charged with commenting on a specific plastic (or polymer) in detail. The focus is on what distinguishes the plastic from other plastics by describing the features that make the plastic unique. The features would involve molecular structure, properties, and industrial, commercial, or consumer uses and applications. You must collect the appropriate information, coordinate your findings, judge the data, and write a report.*
>
> *You will research the plastic from a variety of sources – internet, magazines, journals, manufacturers' datasheets, product literature, books, and conference proceedings. Keep track of all your research sources and be prepared to report on which were more useful. The research should include history of the plastic/polymer; fundamental molecular structure; molecular chain topology; molecular structural features and effects on properties; molecular weight distributions; basic, general mechanical, physical, and chemical properties; and uses and applications.*
>
> *Devise a procedure for collecting your information prior to beginning the project. Choose which informational sources you will consult. Write down the procedure in a step-by-step order. Make sure proper documentation is maintained by complete referencing; use a system of referencing from a writing-style guide/handbook.*
>
> *Present your findings in a written research report. Include data, tables, figures, diagrams, charts, graphs, references, and photos, where appropriate, to better illustrate your findings. The report must have a minimum of four pages of text (exclusive of references and illustrations: tables, graphs, figures, charts, photos, etc.) and be double-spaced with a 12-point font. The report should document and explain the plastic or polymer and its unique features and uses that, in your judgment, set it apart from other plastics and polymers.*

With lecture information, group learning, and homework assignments all reinforcing each other in the learning process, the student is ready to proceed to upper levels of Bloom's taxonomy; this performance task requires a higher-level of thought with judgment, evaluation and planning. Notice how the task is student-centered and uses verbs that promote action by the student.

ASSESSMENTS

Of course, to objectively assess student ability, it is necessary to provide, ahead of time, a scoring rubric specific for this assignment. The rubric covers research, writing, organization, and quality criteria of the work. A partial rubric for Performance Task 2 is:

Criterion	**Score = 3: Good**	**Score = 2: Acceptable**	**Score = 1: Weak**
Reference Use	Pertinent references are used; properly listed at end of report; and clearly cited within body of report.	Mostly pertinent references are used and properly listed at end but much text is not cited.	Little use of references.
Spelling/ Grammar	Few errors.	Some errors.	Many errors every page.
Organization	Topics are logically arranged with good flow between them. It is easy to follow lines of reasoning.	Sometimes difficult to follow topics and lines of reasoning.	Topics are mostly disorganized; hard to follow reasoning.
Critical Findings or Data	Interprets results and data and properly applies interpretations to the conclusions.	Interprets results and data but does not successfully apply interpretations to conclusions.	No interpretation of results or data. No application to the conclusions

Among assessment tools are examinations but these must truly test the material presented in class and be consistent with the SLOs. To accomplish this, an extensive test bank of questions was formulated. Question format was varied with the emphasis on questions that are objectively evaluated. Thus the format uses multiple choice, fill-in-the-blank, item matching, short answer, and true/false; it is important that lower-order as well as higher-order thinking questions are included7. Each test bank item may be characterized as knowledge, comprehension, application, analysis, evaluation, or synthesis, consistent with Bloom's taxonomy. Here analysis, evaluation, and synthesis represent higher-order thinking test items and some test questions ought to be at such levels although higher-order problem solving may be better assessed through performance tasks and their rubrics. For TECH 344, an excerpt from the test bank gives some questions related to basic organic chemistry. The ten sample questions are grouped under student-learning objective *A.1. Students will interpret and draw polymer chains*:

1. The type of bond between two carbon atoms of a polymer is
    a) covalent.
    b) ionic.
    c) dipolar.
    d) metallic.

** For the next 6 items, write the typical number of bonds the element makes in the blank space next to the element.

2. hydrogen _____
3. sulfur _____
4. chlorine _____
5. carbon _____
6. fluorine _____
7. nitrogen _____

8. The molecular weight of heptane is
   a) greater than
   b) the same as
   c) less than

   the molecular weight of heptene.

9. The straight, four-carbon-long chain molecule containing only hydrogen and single bonding is ______________.

10. All macromolecules are polymers.
    Circle: TRUE or FALSE

By grouping test questions under SLOs, direct evidence is given for assuring that a specific area of knowledge is tested. This is a useful asset in national educational accreditation programs as it provides proof of learning, once test scores and data become available. Quiz as well as midterm and final examination questions are selected from the test bank.

Testing should also be done prior to topic presentation, and then repeated to assess a student's prior knowledge as well as the effectiveness of the learning process. For this, as part of a trial, an initial selection of eight retention questions from a midterm examination was made. The questions constituted 16% of the final examination and centered on fundamentals such as classifying a specific plastic (polystyrene, epoxy, nylon) as a thermoplastic or thermoset and drawing the basic chemical structure of polymers including polystyrene and polyisoprene. It was found that students scored 12% better on the repeated retention questions than on the other final examination questions.

This indicates that if special, or extra, attention is given to critical topics, students are able to perform. Different teaching and/or learning models ought to be considered for such topics. This, in conjunction with better group-learning processes, should increase test performance, including performance on retention items. Similar success was encountered with topics such as polymer molecular bonding and plastics property evaluation8; the pre- and post-testing was beneficial in identifying misconceptions regarding these topics. In that study, the testing tool was in the form of concept quizzes that addressed polymer fundamentals including drawing van der Waals bonds.

CONCLUDING REMARKS

Guidelines for adding student-learning objectives, group learning, and student assessments to an introductory plastics course have been proposed, but the full program has not yet been implemented. Once TECH 344 is offered with its revised format, data should be collected to determine whether student learning has improved. Test scores and grades from previous offerings may be suitable as baselines. The goal must be continuous curriculum improvement through analysis of student performance data while also utilizing the data for accreditation purposes9. However, if there were too many uncontrolled variables, meaningful quantitative, statistical findings would be impossible. Nevertheless, qualitative data and instructor experience should provide an early and quick evaluation of the program.

Certainly, reorganization of TECH 344 is expected to be a continual process as more feedback and information arrives each time the course is given. The primary source for course feedback, in addition to testing, is the standard course evaluation, which provides student perceptions on the course structure, textbook, homework, examinations, and instructor; the evaluation provides opportunity for detailed, lengthy student responses. This information, although not as quantitative, must be considered during course modifications over time.

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ADAPTING LEARNING OBJECTS TO E-LEARNING AND B-LEARNING IN MATERIALS SCIENCE CURRICULA

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ABSTRACT

It is important to develop and organize Learning Objects (LOs) on the Web, by following international standards. Although there are many standards that help to create LOs, most of these are very general. This research proposes a methodology that focuses on standardizing each LO according to its context. The proposed methodology includes LOs assembled that are based on the subjects and specific interests of the users and the students. Many important technological, pedagogical and functional factors have been considered to achieve a real impact of such courses. This methodology presents an easy solution to select and assemble LOs. The purpose is to optimize the forms of learning by allowing individualized routes for new courses. The goal is to adapt each LO to generate a higher standard of education and a favorable teaching-learning process. In addition, the coherence in the sequence and union of the LOs should be supervised by teachers. There are many ways to exploit this proposal by individuals, such as professionals, who are not necessarily educators. It is crucial that there be mutual collaboration to improve the education system. The results of this methodology using the test of adjusting kindness as set forth by Kolmogorov-Smirnov demonstrate a normal distribution with a satisfaction degree of 95%. In summary, if the students practice their knowledge the results are considered successful.

1. INTRODUCTION

Wiley[1] defines the Learning Object (LO) as any digital resource that can be used as support for learning. The creation of LOs considers learning to be neither linear nor a sum of knowledge, but is an active individual process that permits one to unite, restore, interpret, enhance and build a skill through the use of different resources and experiences. It is necessary to promote the creation of web resources in a modular fashion for education. Currently, there are several technological educational resources that can be used and adapted for learning support. It is time for teachers to update and collaborate on the development of new open technological didactic tools. In this regard, copyrights are meant to permit various users share and respect the materials that they utilize.

LOs can be developed independently according to educational quality and standards of the Web. In this way, the LOs can be reused in different courses, institutions or disciplines, anytime, anywhere.

This research is also addresses the problem of how to join and create sequences of LOs in a simple manner according to the specifications of adaptation for each e-learning or b-learning course. The goal is to produce the desired knowledge. For the assembly of such knowledge it is necessary to adjust the layout of each LO considering the requirements for improving the teaching and learning process. It is important to consider different factors, including: the final appendices used by the LOs, the designated times for learning and the desired results to be achieved. This proposal give a flexible alternative based on e-learning or b-learning, focuses on providing each student or teacher. The proposal also permits the implementation of courses, with tips, advice and guides for individuals to follow that are appropriate and coherent routes so that the student will gradually cover all course materials and obtain accreditation scores. There are several matters to address in order to achieve this purpose, many of which were considered in this methodology[2]. These aspects are the best way to describe Los, for example proper sequencing of the LOs in order to optimize the content of the courses.

The proposal focuses on creating courses through attractive selection and significant Los which are formed using the following criteria: functional bases, cognitive and rhetorical. e-Learning or b-learning courses which will be relevant provided adequate learning materials. Several studies have shown that ample resources result in superior learning outcomes [2,7-8]. If a course assists the student to master and apply the knowledge taught in the course, then the results are thought to be satisfactory.

2. STATE OF THE ART

In current literature reviews there are famous like Piaget who believed that education should be planned in such a manner that it permits the student to manipulate objects from the environment during their learning journey[5]. It is also important to add variations in the learning or practice until logical deductions are made by developing new schemes and mental structures. Vygotsky is another example of the constructivist current. He considers the crucial social environment for learning, and asserts that cognition is achieved by utilizing instruments, like cultural objects and social institutions such as churches, schools. Vygotsky defined “a zone of proximal development” as the distance between the real level of development and the possible level of learning development generating cognitive change results from the interaction with the instruments that have been transformed mentally[6]. Other researchers have also proposed using semantic technologies in remote Web learning courses[7]. However, few systems have been put into practice since most do not follow any form of LO standardization. One of the frontiers of this research is Casamayor[2] who suggests an adaptable and controlled model for content creation in Web courses. In Ref. 8, another experience of e-learning is demonstrated, that has achieved a success grade of 77%. Another, objectives and content of the b-learning are described in Ref. 9. The investigators demonstrate an experience predecessor based on SCORM using collaborative learning[10]. In Ref. 11[1], the satisfaction and motivation of the environment e-learning for feedback regarding experiences of these environments scanning the competitive effects of e-learning to have an educational high grade was evaluated. Unfortunately in most of these investigations the methodologies do not clearly indicate the use of LOs development in the courses.

3. METHODOLOGY

The proposal herein consists of formulating way to adapt technology to the needs of the users with the possibility of selecting specific LOs. In this way, the student has the opportunity of exploring and developing by managing their own learning and performance acts According to[12], learning can be conceived as a continuous and recurring process, where the apprentices refine and integrate adaptive ways to perceive, think, act and feel which can be considered a means to basic social adaptation.

Mental coding and decoding permit individuals to reach their own knowledge levels which in turn can lead to scientific reasoning. Given all possible variations between different contexts, it is necessary to store LOs in sufficiently rich formats that will maintain their simple adaptation, classification, and combination. In other words, having a great variety of alternatives implies involving a continuous interaction of a set of elements that permits the process and analyzes experiences in distinct courses.

Assisting learners to understand knowledge involves considering context ontology, learning content ontology and domain ontology. Ontology is a formal and explicit description of domain concepts which are conceived as entities, relations, instances and functions[13].

The teachers can determine the appropriate and motivational features of LOs according to specific educational needs. In order to have suitable learning objects the teacher must have complete and unabridged information about it[14].

3.1 Essential elements of the courses and e-learning or b-learning

- Course catalog home page. This must be presented in an institutional manner offering links to each e-learning and b-learning courses. Online courses should have a participant's information record, such as: skills, interests and demands of any kind that is stored for future access and reference.
- Homepage of the course. It should provide a brief welcome and a course description, for example: a general objective and introduction. It should also provide access controls to navigate the course offered and dates when these run.
- It should provide a page that permits users to select the LOs so as to carry out recommendations. It must keep records of the courses taken and / or completed by the student.
- Registration page. A page that provides a simple registration process for the student. Student information must be updated when registering for each new course.
- Pages of topics and sub-topics. These should include a goal and an educational foundation for each LO or activity, such as: provide clear and specific information indicating approximate times frames, suggestions for the development of knowledge and skills, specifications of evaluation and self-evaluation criteria such as metrics to evaluate the actual content, and options for comments and learning feedback.
- Images, sounds and animations of the pages. These must be of a size that is not too big for easy use. This should include learning support material
- Methodology of the course, specifications of operating conditions, theoretical or practical approach of the course and follow-up recommendations for the course.
- Additional pages. Links to additional information, links to necessary information such as participant's profile, glossary, bibliography, e-mail contacts, chat-rooms or forums, activities schedules and homework, etc.
- The underlying attitude of the courses should convey support and trust so student doubts are dissipated.

3.2. Technological aspects of LO

3.2.1. *Descriptive features*

It suggests that LOs possess at least three basic characteristics[15]:

a) Have a logical reference system, labeling that guarantees access.
b) Be reusable that is adapted to different learning contexts.
c) Be able to interoperate independent from the environment.

In order to ensure these characteristics are present[10]. It is necessary consider object-oriented paradigm. Where the following principal behaviors are defined:

- Abstract. Determines the essential tactics and characteristics of an LO.
- Modularized. Makes LOs sufficiently small in order to be reusable.
- Hidden. Hides the technical information
- Encapsulated. Gathers elements of the same identity.
- Polymorphism. There are different references and collections of the various LO functions.
- Inherited characteristics. These belong to classified LO hierarchies; some LOs can be part of a larger LOs.
- Granulated. The size of Los as the LOs can belong to another LO.
- Improved. Maintain quality of LOs. These should be updated according to necessity and receive ongoing feedback. LOs possess qualities that make them useful for learning.
- Labeling. Metadata has to provide relevant information to the LO, for example copyrights.
- Standardization. This is one of the most important characteristics based on standardized LO models that includes the compilation of all the LOs and their metadata. There are regulations that standardize LOs.

3.2.2 *Standardization*

There are many problems regarding interoperability due to many application profiles. It is necessary to have standardization in order to make e-learning o b-learning courses. The standards can be applied in a different contexts, but it is important to consider details of pedagogical aspects. If LOs are properly implemented, the application set up is capable of hosting many institutions so that they have their own repository.

A technological environment of teaching for the process of a standard at international level involves diverse factors. The process to continue can be represented as a leaf as seen later in Figure 4.

IEEE 1484.12 (Learning Object and Metadata Working Group, IEEE Learning Technology Standards Committee 2000). This organization sets forth technique standards to develop software tools. IEEE 1484.12.1 LOM base schema contains items such as: general identifier life cycle, meta-metadata identifier, meta-metadata contribute, technical size, educational clause, educational interactivity, educational learning resources as well as specific kinds of LOs such as: exercises, simulations, questionnaires, diagrams, figures, graphs, slides, tables, exams, and lectures[16-17]. The aforementioned information permits the assembly of LOs for future courses. Furthermore, the ordering and taxonomy of LOs permit adequate management of LO resources. However, the details of pedagogic aspects are not specified in this standard.

Instructional Management System (IMS). Part of this system describes LO and other parts describe certain aspects of Learning Management System (LMS). It is a global learning consortium developing specifications for a wide range of learning contexts. IMS specifications are defined by three specific documents: the information model, the XML binding, and the best practices implementation guide[18].

IMS Content Packaging Standard. Describes the manner of educative contents that must be packaged so they can be used by other e-learning or b-learning, etc. Learning Management Systems (LMS). It is responsible for creating a uniform manner for describing LOs. This standard offers great flexibility when it comes to accepting a great variety of content. The primary objective is satisfying application profiles. In other words, it offers mechanisms that permit acceptance of different formats.

Advanced Distributed Learning-Sharable Content Object Reference Model (ADL-SCORM). The purpose of this is to provide standards that permit interoperability of LO within the LMS. It is based on IMS specifications and Dublin Core techniques. The LO definitions set forth by SCORM offer solutions to represent and use instructional resources with learning activities in a group setting. The dominant features of SCORM are that they specify three main elements: Content Aggregation Model CAM, Sequencing, and Navigation SN and Run-Time Environment RTE. ADL-SCORM is an example of concrete adaptation in IMS Content Packaging. When a series of packaged contents is distributed and describes its structure then a file called *Manifesto* is created which represents the structure of the course in XML using an Application Programming Interface API (API). API is implemented by different organizations[19].

Dublin Core describes a Web resource. The purpose is that LO or resources are easy and efficient to access on the internet.

Extensible Markup Language (XML) is the basis of packages of LO courses. It was created by World Wide Web consortium (W3C). It defined a manifest with Document Content Descriptions (DCD) course organizations and LO metadata. DCD is based on three standards of RDF[20]. The XML objects provide a standard, whose documents and dates are clear and easy to store (documents and dates). XML is the mechanism for the creation of uniform formats of data exchange and thought to be an appropriate tool to check that the emitter and the receptor can access to the data without great effort. XML is a set of rules used to define and validate files of the course. The file result can be a zip[21].

Resource Descriptions Framework (RDF). This is used to define the document structure. One provides a means for the exchange of readable descriptions of petitions for a computer connected to the internet. The petition could be a XML document, or an application of Java. RDF includes sharing petitions with motors of searches[20]. In other words, LOs have to contain certain conditions that permit portable resources, such as: metadata standardization, specific languages, certain sizes, packaging, etc. RDF provides specifications for metadata such as entity models and properties. Entities can be graphics for web courses and properties are characteristics, attributes, aspects, or these can be related to other entities. Properties and relations between web resources are important in creating LO[22-24].

3.3 PEDAGOGICAL ASPECT OF LOs.

3.3.1. *Descriptive features*

Pedagogy outlines the difference between being informed and obtaining knowledge. The pedagogical part of the LOs schematizes and represents the manner by which information is to be transmitted or taught. It is necessary for teachers who are planning courses to consider: How the students can obtain significant learning?

Significant learning has a unique relationship for each person. In Ref. 25, it is asserted that schemes are to be created according to the learning resources that will be used. In Ref. 26, the investigators also considered that these educational developments are a guide or may be optimum methods in order to obtain knowledge. It is inferred that every LO must

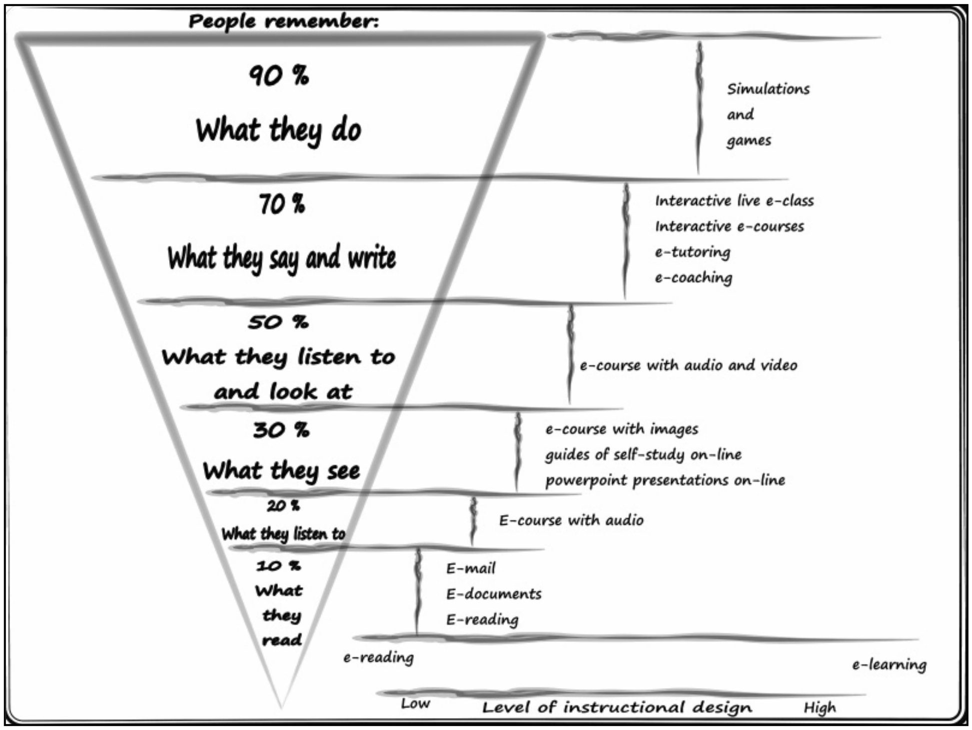

Figure 1. Cone of learning of Edgar Dale[2].

have motivational characteristics that generate knowledge and specific abilities. In Ref. 27, the authors stated that professors have to empower their students through discovery because this is a primary source of internal motivation that permits the acquisition of long-term knowledge such as: applied exercises, demonstrations, workshops and discussions.

3.3.2 *The pedagogy*.

The pedagogy is bound to the ICTs with the purpose of meditating the methods and educational processes. There is a substantial difference between teaching a web courses as compared to teaching a traditional curse. According to Dales´s people only remember 10% of what they read, as opposed to 90% of what they do, see Figure 1[2]. This is why planning interactive activities using the web requires much more intensive e work on the teachers´part to encourage interactions among the students. The discussions should be guided and modeled when they are online, and techers should encourage their students to respond in an assertive manner. This work demands that the professors maintain a facitator role because they should answer student's questions while keeping an eye on them and in order to empower them to reflect more otherwise the students can easily lose interest. In this scenario, the teachers´ role changes; they no only teach, they become designers of learning scenarios encouraging the students to participate and learn, according to their social and psychological characteristics.

It is important to vary didactical techniques in order to obtain better results utilizing differing LO behaviors; therefore, the following factors should be taken into account: a) asset value, b) topics covered, c) work relations, d) different types of learning, e) different types of students, and many others. In any group different students have different ways they prefer to learn, such as the ones mentioned in Ref. 28, for example:

a) The students that utilize their imagination and take actions based on their feelings and observations. These individuals demand to know "WHY". Their learning is derived from concrete experiences or even abstract concepts; such characteristics lie between active experimentation and reflexive observation.

b) The students that assimilate concepts based on reason accompanied by action and observation. They tend to ask the questions: "WHAT" and '"HOW". Their learning consists of a combination of abstract conceptualization and reflexive observation. Most of these students have the inquietude of applying what they learn.

c) The students that analyze, randomly in an abstract manner; they base their learning on their feelings accompanied by action. They try to modify whatever is wrong and can analyze complex experiences.

3.3.3. *Election of didactic technique*

In order to choose appropriate didactic techniques, it is necessary to consider the objectives that one wants to achieve in the learning. It is important to select these techniques and consider the interests of the participants so that the learning occurs in a natural way. Some of the most common didactic techniques are found in Ref. 29:

1. Development of problems to be solved. To foment integral solutions so that students will be able to analyze different factors those interacts within a problem and then formulate different alternative solutions.

2. Collaborative learning or sociability. Different combinations of people and different times are encouraged in order to achieve mutual help, interaction, critical valuation, investigation and dynamics, etc.

3. Practical experiences. It is important to examine, meditate and apply the concepts that have been acquired to experience concrete learning.

4. Explanatory.- Presentations preferably made by experts, in situations such as:
   a) Conference and Symposia. Presentations from research experts.
   b) Roundtable. Discussions involving 3-6 people espousing theories, concepts or divergent views on issues in a common, informal atmosphere with the aid a mediator argumentation and consensus).
   c) Guidance. It is clearly presenting concepts or theories, preferably related to the students' interests.
   c) Receptive. In the past, this was a common method of teaching where the teacher was active and the student was a listener.
   d) Brainstorming. The emergence of new ideas in a group setting in an informal environment regarding specific topics or certain problems, this facilitates student creativity.
   e) Questions and answers. Interrogations that lead the students to participate in discussions and analysis, inquiry, reflection and understanding.

5. Playful. These are recreational, even amusing activities, games or competitions that also inspire learning, contents and topics. Qualities, interests and overcoming obstacles are fomented.

6. Case studies. These are based on the description of a real or fictitious situation, there is a problem in which the students must arrive at the approval of a single solution.

7. Simulations. Virtualized real practice activities intended to achieve results without investing in real cases.

8. Laboratory Investigations. Here one or several interrelated phenomena are presented and contradictory theories as well, using scientific evidence to draw conclusions relevant for the students' professional practice.

9. Directed and guided activities. Presentations of instructions meant to generate discovery with guided learning.
10. Reinforcements. Activities created with the specific purpose of strengthen other skills.
11. Accreditation. How is it validated? How to do evaluations and give feedback contribute to content? Surge assessment activities in differing? Nuances, for example: cumulative summative, diagnostic, formative, conceptual, procedural and attitudes. In short, learning must be easily proven in order to be evaluated[29].

The didactic spaces are propitiated and students tend to favor the interactions utilizing digital resources. They will consequently learn more efficiently. Moreover, acceptance of Bloom's taxonomy[30] is widespread with curriculum designers. It considers six different levels of cognitive skills: 1) knowledge including factual recall, 2) comprehension including the understanding of information and the grasping the meaning, 3) application meaning the ability to use information and solve problems, 4) analysis encompassing the ability to see patterns and discover the covert significance of material, 5) synthesis indicating the ability to create new ideas and to generalize from available information and 6) evaluation as being the ability to compare and discriminate between ideas and to assess the value of different theories. The activities of the learners must have a relationship between the learning outcome and their respective cognitive levels.

3.4. Functional Aspects of LOs

It permits the presentation or observations of the materials as many times as is necessary by the participant, as well as the results that are obtained, (see later in Figure 4).

3.4.1. *Sequence of those LOs*

It is given that in the future the trend will be to use LOs, their selection and the way in which they are intergraded may well determine whether sequencing is adequate to achieve superior learning. The sequencing determines the structure and flow of course content. The sequencing can be determined by the students. They are offered recommendations and resources that will achieve meaningful learning. It should stimulate the interest of each participant; therefore it is important (for every stage) to outline the benefits that can be obtained at each stage of learning, as well as surveys and/or prizes for participants efforts. The sequence selected and/or recommended for the students can be given with different topologies, see Figure 2: tree, star, circular, spiral.

In order to make recommendations it is important to define what the best topology is considering the objectives of learning in particular subjects, because according to the topology, the search engine will have access to certain LO combinations. A complete topology includes all the necessary LO nodes. It can define several relations between nodes such as outbound or return or in both directions. The Relations, will also determine when permission will be granted to an individual student during the selection and sequencing of LOs. Self-directed learning is often more satisfactory. In other words, each participant creates their own path to personal rhythms promoting the customizing of certain learning topics or themes.

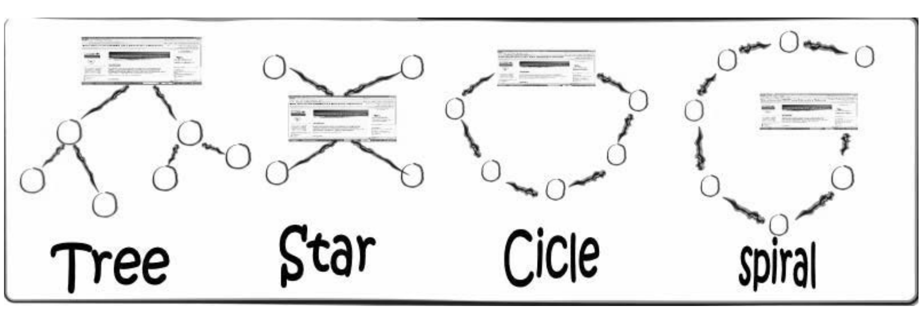

Figure 2. Topologies of LOs.

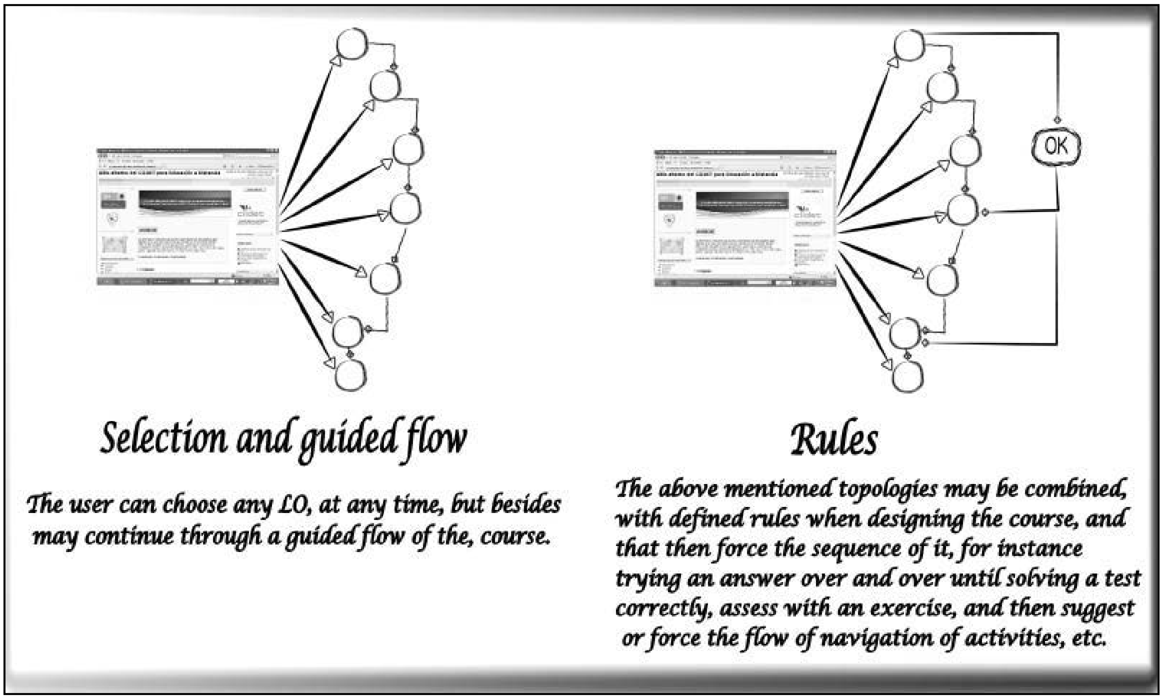

Figure 3. Some possibilities of sequencing content of LOs.

With the support of SCORM, a sequencing of rules for LMS can be provided in order to decide which activities to do and in what order the learning is acquired, see Figure 3. The sequence determines the order of topics and subtopics. This process is also called the instructional role. In this process, educators have to be careful with the parts used whether: cognitive and rhetoric. The cognitive part will determine the quality, motivation and clarity of contents in the process of decoding knowledge. Furthermore, taxonomies of Merril, namely facts, principles, concepts and procedures can be utilized for details[31].

The search engine results indicate the success or failure of the students browsing within the course. The access to information is defined to handle the database, for example, in MySQL:

- SELECT C.Learning, L.Type_of_LO, U.Time
- FROM Student AS S, Los AS L, USE History AS U
- WHERE (S.ID_Student=1050)

  AND (S.ID_Student= L.ID_Student)
  AND (S.ID_Student= U.ID_Student)
  AND (U.Time=9:00:00-12:00:00);

Moreover, the LO connections determine the routes that each student selects. This route can be a minimal or maximum one. The routes can even be presented as separate unfinished business islands. For sequencing it is essential to provide increase of knowledge of Los available. For access routes to LOs, it is suggested that there be as many methods to learn available as there are individuals. In other words, the probability of repeating sequences and times for under-taking course is minimal. From the point of view of a pedagogy, a teacher's task is challenging because it is not enough to just pretend that you are teaching; just as you can not pretend that you are learning.

3.4.2. *Specifications of the user*

Figure 4 shows the key elements for achieving learning experience through this methodology, focusing on the interests and needs of the

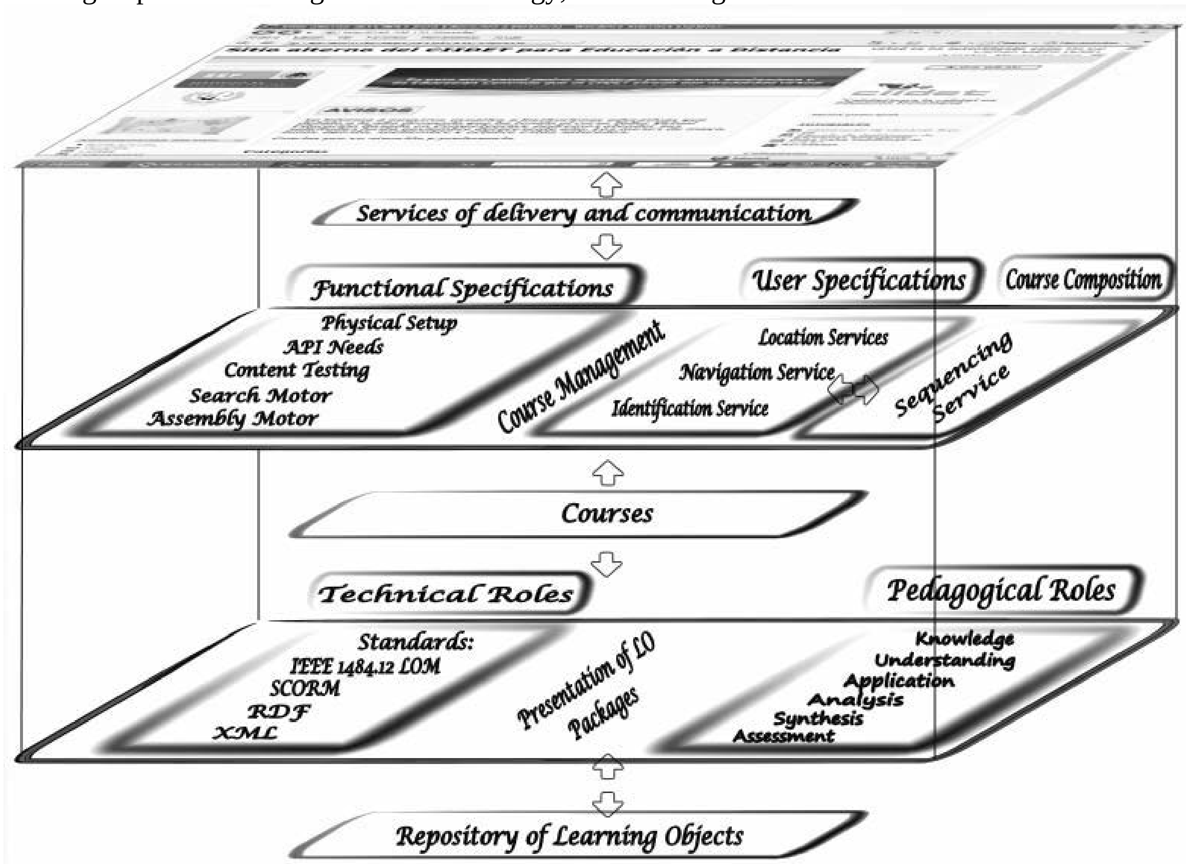

Figure 4. Architecture of courses with LOs

student. It is presented from the most abstract elements, the early stages of design, to the more specific elements that involve the completion of the process, from which the following can be observed:

- Location service. Perform a search and recovery of LOs in a number of repositories which can be file servers, LOs Libraries or Learning Systems Managers.
- Monitoring service. Keep a record of successes or failures when using LOs and/or the activities of the participant to identify their specific needs during the course.
- Navigation Service. Keep track of lessons and unfinished sections or parts of the course. This is linked to the sequencing service, which provides LOs classification in regards to the predefined topics and instructions.Identification Service. It automatically generates metadata for a basic LO multimedia resource. This is what permits a user to convert any media file into a learning object?

3.4.3. *Accessibility in the handover service*

Physical installation of the content package. Check if there is a match between Manifest relations (IMS) and its internal structure in order to perform the installation.

- API Needs. Standardized interface for each course according to the LMS.
- Checking the contents. Confirm if they meet the IMS standard.
- Search engine. Locate each LO according

to its metadata, XML content and the requirements of the student.

- Motor assembly. Connect routes or paths for each activity of themes and sub-themes. Through metadata, the resources are referenced as an element of an organized repository of products for different courses.

3.4.4. *Management of curses e-learning or b-learning*

The administration of LOs can be done in different ways, ranging from simple management of databases or directories, to complex and specific features of databases with LO packed structures. The administration of courses permits the presentation and access to LOs which considers different aspects such as the ones listed in Figure 3:

This methodology was applied to three pilots thematic units of the subject "Analysis and Systems Design "in 2011. Two of these were carried out within the scheme of e-learning and the final within the scheme of b-learning. The LOs were conducted with support from LECTORA, FLASH and other software to make them more attractive. These were compiled for their standardization in LECTORA and in RELOAD. XML Packaging was introduced in the LMS- MOODLE. By using MOODLE the students have the opportunity to sequence the LOs with their respective activities according to individual learning needs. The sequencing and assembly were flexible enough for both students and teachers. The results were obtained from a sample of three teachers and 104 students who were surveyed.

4. CONCLUSIONS

Today, educational context is considered more important to the vertiginous advances in technology than their repercussions on learning. Proof of this is the different virtual educational modalities, e-learning, b-learning, c-learning and m-learning. In other words, it does not lose sight of the fact that the essence is not the prefix. The essence is the learning, because technology must enhance learning necessities.

Throughout the development of the project, a number of requirements for content adaptation in the LOs were identified. Why have the writers of these programs not modulated these tasks to make them easier? The results of this methodology which makes use of IEEE and SCORM standards produced satisfactory results for the use of new technologies in education. In Figure 5(a)-5(e) the results of the survey carried out for the teaching unit of Design and Systems Analysis can be seen.

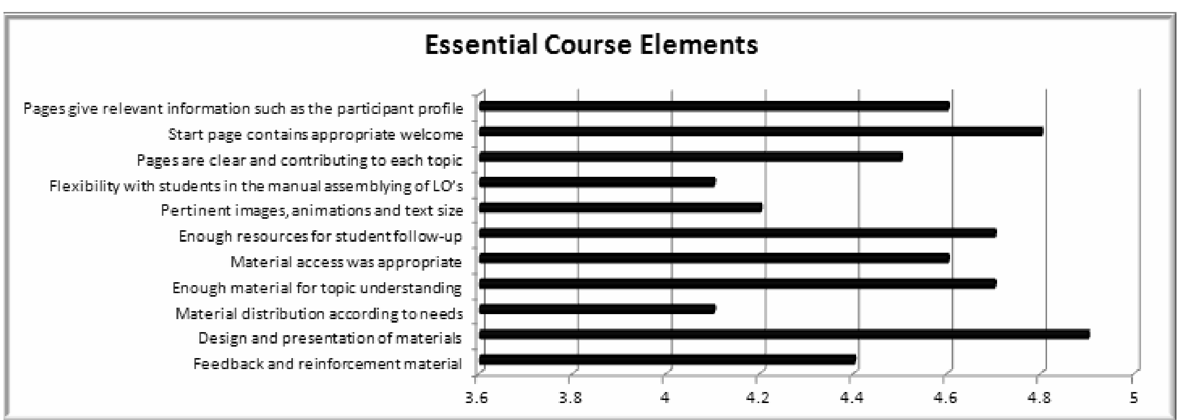

Figure 5(a).

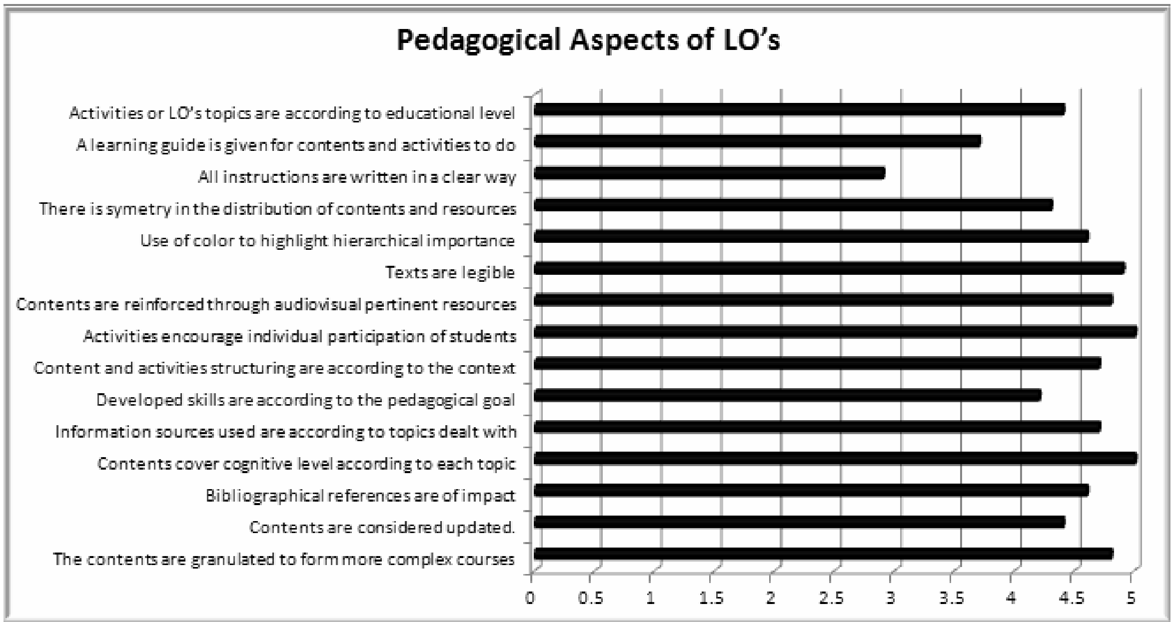

Figure 5(b)

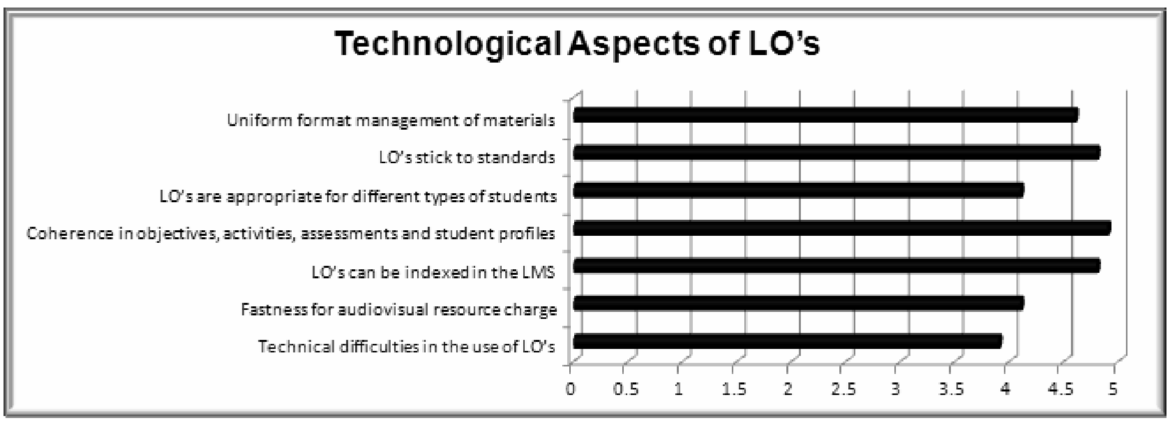

Figure 5(c)

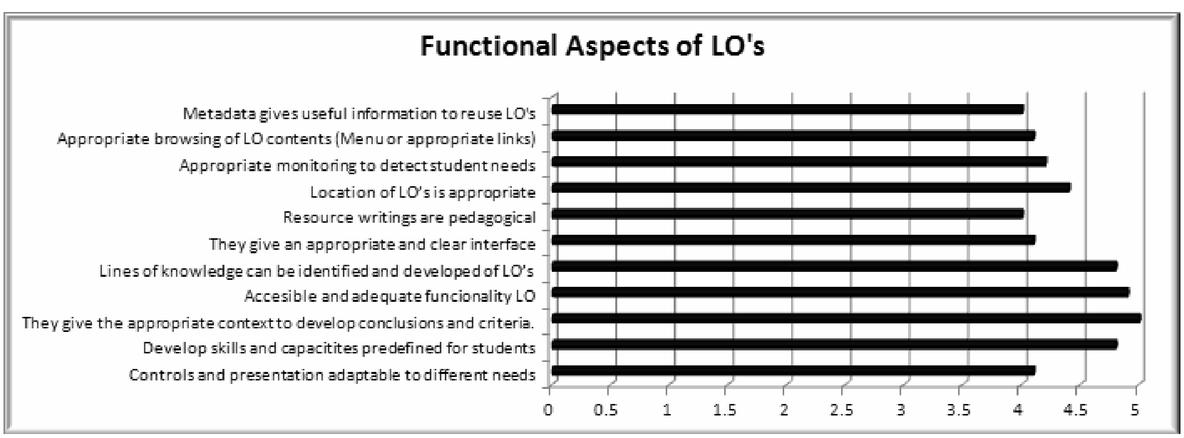

Figure 5(d).

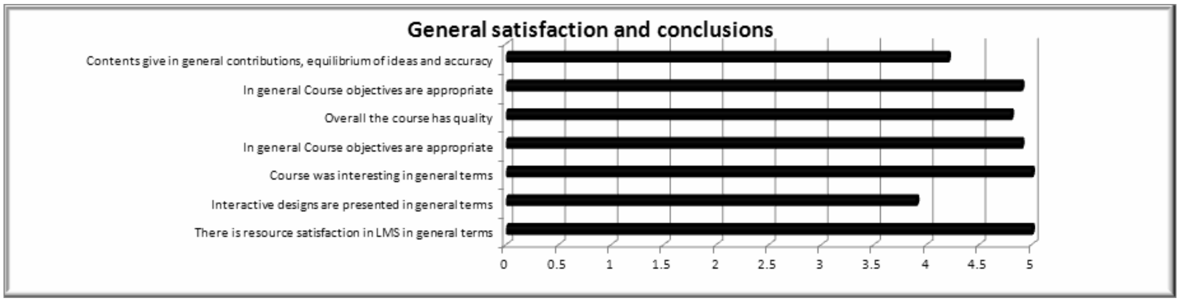

Figure 5(e).

The implementation of the educational units showed that it would be wise to invest more time in the tutorials, instead of in the preparation of courses. When this methodology is applied actual working time was reduced by up to 20% as compared to traditional methods with which these courses were usually taught. In other words, an excellent alternative was offered in order to teach the courses with these modalities. At the same time, it generated a new flexible ways to learn, fulfilling the objectives of efficiency and effectiveness while optimizing educational resources.

Other details obtained from the XML packages indicate that these materials are harder to read than HTML. Consequently a decision was made to convert some resources to this format[32]. It is also suggested that backups of each LO component in their original formats be kept whether these are audio, text, animation, presentations. The feedback regarding the XML files responds to meet the needs of each database. The results that were obtained using the test of kindness created by Kolmogorov-Smirnov demonstrate that the methodology wasn't rejected by the students using the learning units in e-learning or b-learning. Furthermore, as is indicated by the normal distribution, these were thought to have a 95% rate of confidence and satisfaction, see Figure 6.

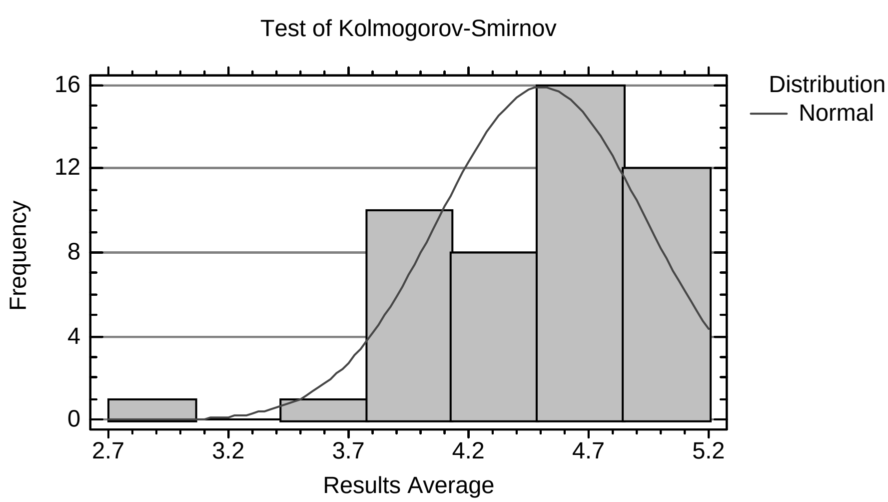

Figure 6. The test of adjusting kindness of Kolmogorov-Smirnov

In other words, this methodology resulted in a substantial improvement in the teaching-learning process. In short, this proposal based on the Web ensures interoperability, reusability, adaptability and effectiveness and efficient optimization of teaching resources to make e-learning or b-learning courses. For future investigations one of the key challenges will be to overcome the outside interference in e-learning or b-learning courses. A better means to attract the interest of participants needs to be created so that priorities and rewards can be established from the onset.

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A LATERALLY AND VERTICALLY INTEGRATED OUTREACH PROGRAM TO INCREASE PARTICIPATION IN BIOMATERIALS-RELATED ENGINEERING

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ABSTRACT

We describe a University bioengineering program that vertically integrates outreach from the elementary through the college level. It was developed as part of a multi-investigator grant targeted at increasing diversity in engineering through biomaterials. However, the approach is not tied to a particular discipline. We offer this model for small groups of investigators to maximize their research's broader impacts while minimizing the burden on any one faculty member by laterally distributing outreach responsibilities. Since our program was established in 2006, we have initiated 169 outreach events including 124 visits with K-12 schools and have interacted with 7,788 people, 73.8% of whom come from populations typically underrepresented in science and engineering.

Keywords: *K-12, outreach, minority, broader impacts*

INTRODUCTION

It is widely acknowledged that the number of engineering degrees awarded to women[1,2] and under-represented minorities[3-6] falls short of their demographic representation. That the scientifically educated population does not reflect our communities is not just a numbers disparity. Rather, it is a waste of valuable intellectual capital that could offer innovative solutions to today's ever more complex problems.

Many universities have initiated K-12 engineering and science outreach programs with the goal of generating and supporting a pipeline of enterprising female and minority students. As noted by Jeffers,[7] these programs range from the development of classroom materials and internet resources[8] to summer camps and demonstrations presented by college students and/or faculty in K-12 classrooms.[9-13] For K-12 teachers who are uncomfortable teaching engineering, these programs may be the only exposure to engineering concepts their students receive.[14]

In order to provide multiple opportunities for local students to learn about engineering before they make decisions about college, many universities have developed programs that integrate their efforts over the entire K-12 grades. In 2005, Lyons and Ebert found more than 150 large-scale, University-supported "Centers" in operation for this purpose,[15] many of which had formed partnerships with K-12 school systems.[16,17]

Not every Principal Investigator (PI) or University is able to create, conduct, or maintain large-scale, institutionally sustained programs, however.[18] Moreover, while small outreach programs are rewarding to students and faculty alike,[18] the development and implementation of outreach projects often falls on junior faculty,[9,11,17] requiring time that detracts from other endeavors, such as research and proposal writing, which weigh heavily in tenure decisions. Developing an effective and integrated outreach program may seem out of reach.

This paper describes our smaller "vertically-integrated" (elementary through university) program composed of K-12 and community college classroom visits, on-campus activities, service-learning, and professional development, all geared to biomaterials. It was developed by our group of five PIs (three of whom were junior tenure-track faculty) from a single grant. We have structured our program to limit the demands on any one faculty member by rotating the position of Outreach Director and by delegating "matured" elements to graduate and undergraduate volunteers (i.e., lateral integration). We maximize our impact by concentrating on one cluster of schools: Albuquerque High School (AHS) and the K-8 schools that feed into it. This cluster serves a large minority population, with most students coming from families with low economic status (65% of students are eligible for free or reduced lunch[19]). This focus also provides the opportunity to interact with the same students over their school careers and to develop relationships with their teachers who help identify promising minority and female students as they progress. Now in our sixth year, there are at least 10 students whose interest in engineering we helped pique in the K-12 classroom or who started as high school interns or community college students and who are now undergraduate or graduate students in our program. In 2011, the first two Hispanic students from this pipeline received their doctorates.

While our outreach has a defined theme and history, our approach can easily, be adapted to the research focus of a wide range of researchers who choose to adopt it. We thus provide an efficient model for individual and/or small groups of PIs to set up their own outreach program.

STRUCTURE OF THE OUTREACH PROGRAM

Source of Initial Funding for Program

In 2005, the Biomaterials Engineering Outreach program at the University of New Mexico was founded as part of a grant from the National Science Foundation (NSF) awarded to PI and co-author Gabriel López. The grant, entitled "UNM-Harvard: Partners for Leadership to Enhance Biomaterials," was awarded via NSF's Partnerships for Research and Education in Materials (PREM) program. López designed the PREM grant to fulfill both research and educational objectives. The group's research interest in biomaterials engineering dovetails with the educational goal of engaging students from minority and economically disadvantaged communities, where health disparities are often pronounced. This choice was influenced by studies suggesting that tying science to societal issues through cooperative and interactive learning increases participation by under-represented minorities and women in science and engineering.[20] Indeed, the American Society of Engineering Education guidelines for K-12 outreach stress hands-on, standards-based outreach emphasizing the social relevance of engineering.[21] Focusing on a biology-based, health-related, and people-oriented subject is also an effective strategy for recruiting women.[22] Moreover, hands-on activities enhance learning outcomes.[23]

Specifically, we pair biomaterials-related research performed at UNM by López and co-PIs (Heather Canavan, Elizabeth Hedberg-Dirk, Julia Fulghum, and Dimiter Petsev) with collaborators at Harvard University (Kathryn Hollar, David Mooney, Kevin Kit Parker, David Weitz, and George Whitesides). PREM research topics include high performance materials for low cost diagnostics (López), smart materials for manipulating cell/surface and cell/cell interactions in 2- and 3-dimensions (Canavan), emulsion droplets for high-throughput DNA sequencing (Petsev), and bioactive materials for engineering cellular function (Hedberg-Dirk).

The PREM's educational objective extends both through biomaterials-related research at UNM and through outreach to our community. In both cases, we are cognizant of the importance of role models in influencing the attitudes and participation of women and minority students in science.[24-27] As our PREM faculty and students are diverse (44% female, 51% Hispanic, Native American and African American), our interactions with K-12 students are intended to challenge the stereotype of the white male engineer.[28] In addition, we aim to steer students towards college-based careers that will help serve their families and communities.

Participants in the Program

All PI, co-PIs, students, and staff supported by the PREM grant participate in outreach. The roles of these individuals and the K-12 partner are described below.

<u>UNM Outreach Director.</u> This is a yearly rotating position assumed by each co-PI in turn so as to reduce the burden on any single faculty member. The Outreach Director is primarily responsible for developing demonstrations used in the schools. Our first Director developed a fifth grade activity plus one based on her research for high school (see "Elements" below). The second Director created a new eighth grade activity and high school program and so on up to professional development for teachers and undergraduate seminars at two-year colleges. In compensation for the extra duties, the Outreach Director draws additional salary from the grant.

The overall workload for the incoming Director does *not* increase each year because "matured" elements from one year are passed to an experienced pool of student volunteers the next. For example all fifth grade visits in Year 2 were conducted by graduate and undergrad students (who were "trained" in Year 1); in contrast, the majority of all fifth grade visits (89%) were conducted by faculty members with graduate student assistants in the first year. (See Figure 1).

Each outgoing Outreach Director serves as an unofficial advisor to the next Director. While this transition requires time on the part of the outgoing Director, the new Director brings fresh ideas that revitalize the program each year. Another benefit is that each PI gains valuable experience working with young students and learning how best to relate their work to a lay audience.

One of the downsides of this model as initially conceived was that the Director was responsible for recruiting student volunteers and for supervising the administration of assessment surveys. Both of these duties were time-consuming, and in the case of the surveys, we discovered that the change of Directors led to some inconsistencies in how the surveys were implemented. To ease the time burden on the Directors and to ensure continuity, we shifted these responsibilities to the Outreach Coord-inator (see below).

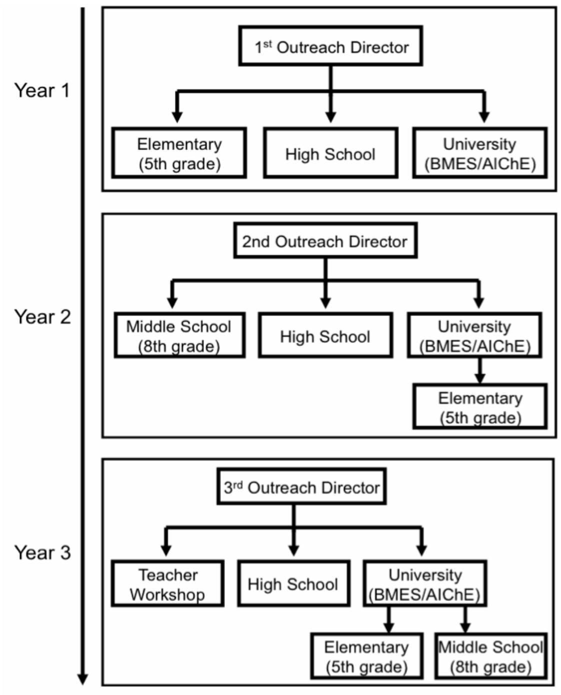

Figure 1. Schematic illustrating the structure of the UNM Outreach program, including the role of Outreach Director during its first three years. Although individual elements are added over time, the Director's relative workload does not change. Instead, matured elements are delegated to volunteers supervised by the Outreach Coordinator.

UNM Faculty. The remaining co-PIs participate in a few outreach events each year, including K-12 school visits, hosting tours for students visiting UNM, and mentoring high school interns and University students conducting research in their labs.

UNM Students and Post Docs. Graduate and undergraduate students give presentations and facilitate activities during school visits. Graduate students may also lead lab tours and mentor undergraduates and high school students, giving them valuable hands-on experience in teaching and participating in service learning.[29] Students involved in service-learning have a deeper understanding of subject matter, increased motivation, and are more likely to take part in community service after graduation.[30] In fact, one reason that many outreach programs incorporate service-learning may be that it helps meet the Accreditation Board for Engineering and Technology (ABET) 2000 Criteria,[31] such as understanding the impact of engineering solutions in a global and societal context. Furthermore, Hobson notes "…such programs enhance the engineering curriculum by linking engineering directly to improving society, which makes the profession more appealing and diverse."[32] Finally, PREM-supported postdoctoral fellows have gained teaching experience in core chemical and biomedical engineering classes to strengthen their teaching skills for their tenure-track applications.

While all PREM-affiliated students are required to participate in outreach, many non-affiliated students ask to be included. For instance, our program is supported by student societies among the larger student population. The undergraduate Biomedical Engineering Society (BMES) assembles the prosthetic finger kits for our fifth grade outreach as part of their fall meetings. BMES has also elected to use a portion of the funds made available to them through the University to purchase finger kit supplies. In Year 1, our volunteers assembled ~250 kits for elementary school visits, with another 350 for the International Science and Engineering Fair, which was hosted by Albuquerque in 2006. Given that the cost of each kit is ~$1, this led to an estimated savings of $600 per year.

Not having their own outreach projects, several other engineering faculty members regularly encourage their students to participate in our program, and they often give presentations and tours to broaden the impact of their research in conjunction with our activities.

UNM Outreach Coordinator. In this PREM-funded half-time staff position, the Coordinator acts as liaison between UNM and APS, contacting teachers and/or principals, scheduling school visits and briefing teachers about the activity. The liaison discusses vocabulary words and concepts that should be understood by the students in advance of the visit, as well as any equipment needed for demonstrations. The Coordinator also recruits UNM students and faculty for outreach events, participates in and documents these events, supervises assessment data collection and serves as a point of contact for the public requesting information, tours, or interviews with faculty. She also gives presentations to community colleges and in other venues as needed. To orchestrate these events with volunteers, we recommend using a website such as "Volunteer Spot," which displays the details of each outreach opportunity and specifies the number of volunteers needed for each task.[33] The site automatically sends out initial and reminder emails to volunteers and provides a link with which they may sign up. Our particular Coordinator has a background in science, science journalism and educational outreach, but a person with educational exper-ience would be equally suitable. A coordinator is a unifying force when students from different majors and backgrounds and faculty with different research interests participate in the program.[34]

K-12 Partner. Our partner for K-12 outreach is the Albuquerque Public School (APS) district. With more than 89,500 students, APS is one of the largest public school districts in the country.[35] In addition, APS serves a significant number of students from traditionally under-represented minority populations, especially Hispanic and Native American students.[35] Table 1 presents demographic information compiled from the 2010 US Census.[36] The number of Hispanic students in APS elementary schools and Albuquerque High School (AHS) (60% and 72%, respectively[19]) far exceed the state and national averages (46% and 16%, respectively). With our focus on outreach to the AHS cluster, we maximize our impact among minority students. We also visit APS charter schools designed to serve Native American and African American students.

ELEMENTS OF THE OUTREACH PROGRAM

Table 2 illustrates the annual schedule of events for our program, which include some of these program elements.

Elementary school. As Genalo *et al.* note, young children at the elementary school level are "natural engineers" with strong impulses to investigate, construct new things, and create.[37] Outreach can reinforce those tendencies and provide students with their first introduction to engineering. For our fifth grade module, we developed an interactive talk about what a bioengineer does, what biomaterials are, and how they are used in people's bodies as prosthetic implants. Then students are asked to design, build, and test a prosthetic finger with a kit made of dowels, rubber bands, and other everyday objects. We chose to target fifth graders for our "bioengineering a finger" exercise because the fifth grade curriculum explicitly includes parts of the body and how they work together. It is also around this age that students start to think about functional aspects of a design more than its perceptual or structural qualities.[38]

We designed this interactive demonstration with the help of a teacher to address a number of benchmarks at both our State and National level.[39,40] We published a manuscript describing the necessary elements in detail.[11] A bilingual presentation, vocabulary words, standards, and a rubric for evaluating the fingers is available for download from our website.[41]

Middle School. While interest in engineering and science is high in the elementary grades, interest wanes in middle school,[24] especially among girls and minorities.[14,42-44] Unfortunately these formative years are when students start thinking about careers, and they may opt out of the science and math classes necessary for the pre-college Science, Technology, Engineering and Mathematics (STEM) pathway in high school if they don't see a role for themselves in science or engineering careers.[14] This is where the diversity of our UNM students is especially helpful as they relate their personal stories of how they found their way to college and the opportunities available to local students.

As in the fifth grade module, the eighth grade unit features an interactive talk, which includes career information about engineering. This

TABLE 1
Population Characteristics: APS, UNM PREM Participants, NM, US

Population	Female (%)	Hispanic (%)	Native American Alaska Native (%)	Other URM (%)
Total Albuquerque Public Schools (APS) (17% Eng. lang. learners; 56% free/reduced lunch)	49.0	57.6	5.1	4.0
Total APS Elementary[a]	48.8	60.1	5.3	3.9[b]
Total Albuquerque High School (44% reduced lunch)	51.4	72.2	3.7	5.6[c]
UNM PREM Undergraduates	48.7	46.2	7.7	2.6
UNM PREM Graduate Students and Post-doctorals	38.7	38.7	6.45	6.45
UNM PREM Faculty	60.0	20.0[c]	20.0[c]	0.0
Population of New Mexico	50.6	46.3	9.4	2.2
Population of the United States	50.8	16.3	0.9	12.8

[a]At some individual schools we visit, over 90% of the student body is Hispanic and more than 97% are on free or reduced lunch; [b]Includes only African Americans; [c]one faculty member has Hispanic and Native American ancestry; 2009 APS data from ref. 19 and 35; US and NM data from ref. 36.

hands-on project teaches polymer cross-linking using alginate "slime."[10] These concepts are related to the research of PREM co-PI and the Year 2 Outreach Director (co-author Hedberg-Dirk). As with the fifth grade module, the middle school module addresses State benchmarks and AAAS guidelines. We chose the eighth grade because that is when Albuquerque students learn about atomic structure and molecular organization. For both the elementary and middle school visits, we find that having four UNM volunteers per class is ideal.

High school. As high school students are close to deciding where (and if) they will go to college, our outreach is comprehensive. We focus on 10th to 12th grade students in Albuquerque High School (AHS) academies who have self-identified as interested in engineering, technology, or health. Figure 2 includes photos compiled from the various "hands-on" outreach elements.

As with the fifth and eighth grade modules, the interactive talk is developed by one of the PIs based on research ongoing in his/her laboratory.

Table 2
Typical Outreach Program Schedule

Academic Year	Fall	Outreach Orientation – go over interactive presentations, activities and strategies for interacting with younger children Assemble 5th grade Prosthetic Finger Kits & Pizza Party – PREM, BMES and other students Visits to 5th grade classes – Making Prosthetic Fingers ~5-7 schools (2-5 classes/school) ~1 hour per class ~4 UNM volunteers/class ~15 minute interactive, bilingual power point presentation Prospective High School students from Albuquerque High School gifted class apply and are interviewed for placement in laboratories for Mentored Internships; they receive high school academic credit Tours of laboratories and hands-on activities given to visiting K-12 classes and during School of Engineering Open House Presentations by faculty, staff and graduate students at Southwest Indian Polytechnic Institute (SIPI) and other two-year colleges and UNM branches around the state Other activities as they arise including outreach table at State Fair, presentations to New Mexico National Science Teachers Association, teachers workshops, mentoring Lego League teams
	Spring	Visits to Middle School Science Classes – Making Alginate Polymers ~2 schools (4-8 classes/school) ~1 hour per class ~4 UNM volunteers/class ~20 minute interactive, bilingual power point presentation Visit to Albuquerque High School by faculty and/or staff Talk and/or hands-on demonstration Faculty, student, staff presentations at SIPI and other two-year colleges Tours of laboratories and hands-on activities given to visiting K-12 classes Other activities as they arise including Science Fair judging, presentations to The Art of Systems Biology and Nanoscience conference, American Indian Engineering and Science Society conference, table at career fairs
Summer		High School Paid Internship program (~8-10 weeks) Faculty, student, staff presentations at SIPI and other two-year colleges Staff presentations and activities and/or tour for the School of Engineering pre-college science and engineering camps for underrepresented minority students

Figure 2. Images illustrating the "hands-on" approach of the UNM integrated outreach program. Elements of the program include visits to classrooms by UNM students, Post Docs, and faculty (top left); visits by high school students to UNM laboratories (above); and mentored research projects for undergraduate and high school students (left).

In one year, for example, the talk pertained to cardiovascular tissue engineering. Prior to our visit, the AHS Health Academy teachers incorporated related topics into the curriculum (e.g., students learned about the biochemistry of the heart in chemistry; they learned how to measure the volume of blood flow in a blood vessel in math classes). Following the talk, the students played the "Name that Implant" quiz to identify the function of unknown implants from a "Medicine Bag." For the most interested and qualified students, we arrange a visit to our Department, including a laboratory tour and a brief talk introducing them to UNM. Students are then invited to apply for a paid summer internship in our labs or for an internship during the academic year for which they receive high school credit. Guided by an AHS teacher, students learn how to write a resume and application, ask for reference letters, and perform in interviews. Because many local students are the first in their families to consider college, our mentors not only model how science is conducted, but also provide coaching on the next academic and career steps to becoming an engineer.

University. In addition to their roles as outreach volunteers, UNM undergraduates, graduate students, and Post Docs are served by the Biomedical Engineering Outreach Program. For instance, PIs give preference for PREM funding to students and Post Docs who are female or members of under-represented minorities, and this in turn attracts more women and minorities to our program.[45] Working with student professional societies in our Department (e.g., BMES and the American Institute of Chemical Engineering), we have designed workshops and lectures on such topics as how to apply for fellowships and scholarships; career opportunities at National laboratories and in industry; how and why to apply to graduate school; how to make a poster.

ASSESSMENT OF THE UNM OUTREACH EXPERIENCE.

Because the success of this outreach model rests on student and post-doctoral volunteers, it is imperative that they support the program. In our surveys assessing the outreach experience of UNM PREM students, a total of 31 unique individuals have responded to date. Of those, 11 (35.5%) were undergraduates and 20 (64.5%) were graduate students. Women accounted for 61.3% of the respondents, and independently, 60.9% of reporting participants identified their ethnicity as Hispanic.

Asked to rank their reasons for participating in outreach on a scale of 1 to 7, where 7 is the most important, PREM students and post-doctorals cited the top three reasons for doing outreach as: 1) "to attract younger students to science and engineering" (Mean ranking for whole group 4.8 ± 2.2); 2) "fun or enjoyed doing" (Group Mean ranking 4.5 ± 1.9); and 3) "a desire to contribute" (4.3 ± 1.5). As shown in Figure 3a, there are no statistically significant differences between the responses of undergraduate and graduate students.

Responses to open ended questions in the surveys provide further insight into the outreach experience. These responses were fairly typical of those obtained when students and Post Docs were asked what they enjoyed most about their experiences:

- *I love interacting with the children. It gives me great joy in seeing them learn. I feel like it is making a difference.*
- *I enjoy being a role model for young minority students.*
- *Interacting with K-12 students always brings a new perspective to my research and keeps me motivated to continue my education.*
- *I love seeing how interest grows in children in the few minutes that we spend with them.*

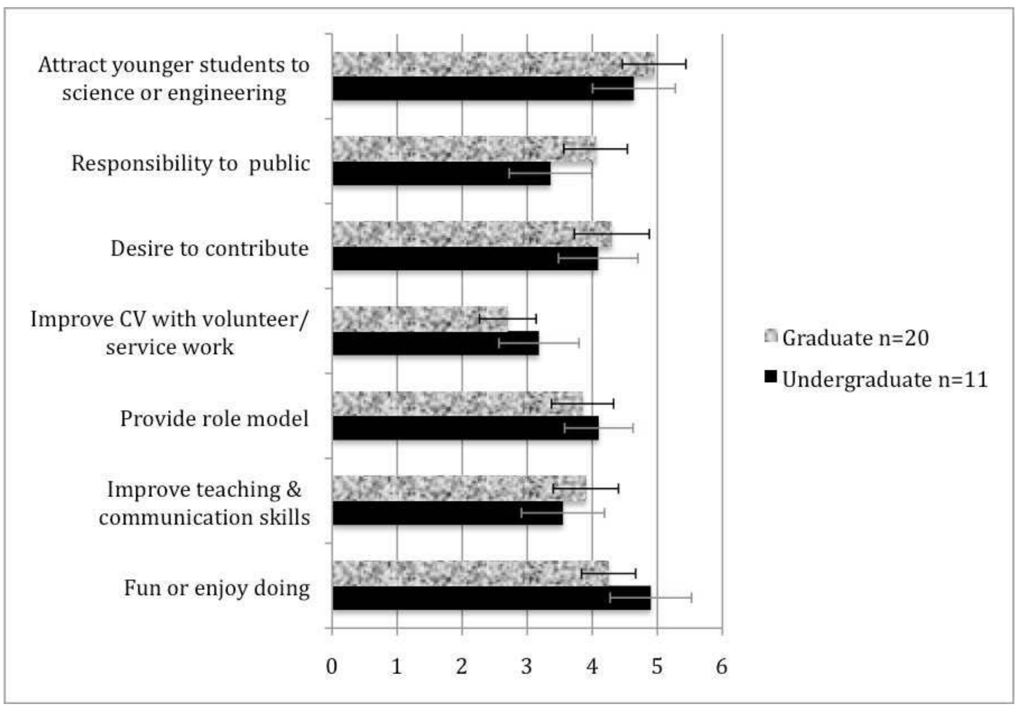

Figure 3 (a) Survey results of UNM outreach participants. In Fig. 3 (a), students and Post Docs were asked to rank their reasons for participating in outreach on a scale of 1 to 7, where 7 is the most important ranking. The graph displays mean ranking. Error bars reflect the standard error of the mean. Figure 3(b) shows the mean ranking of how often obstacles to participation occurred on a scale of Never (0) to Always (4). The only statistical difference between graduate and undergraduate students is that lack of time was more of a problem for undergraduates than for graduate students.

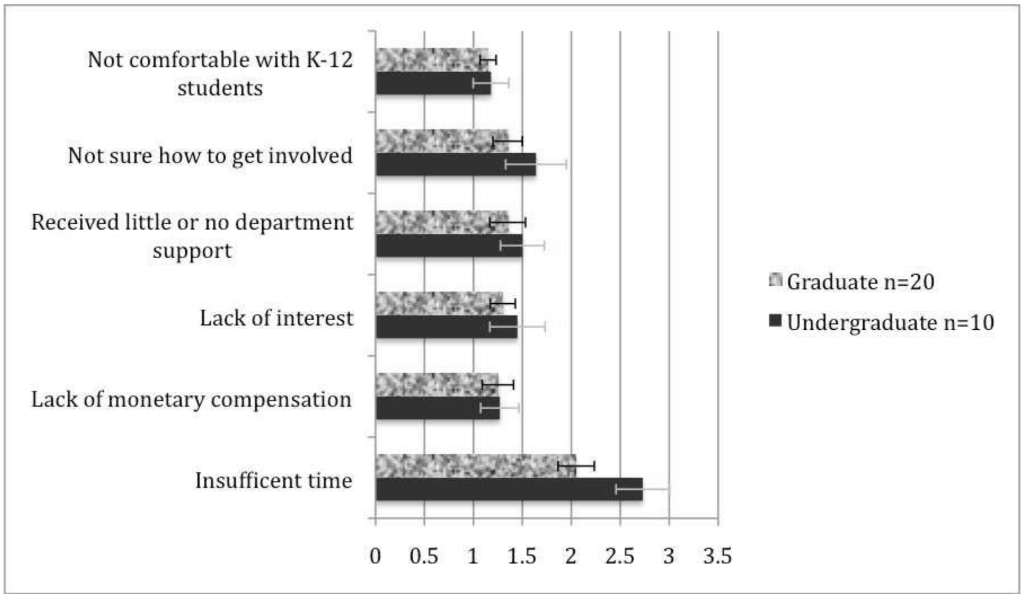

Figure 3 (b) Survey results of UNM outreach participants. In Fig. 3 (a), students and Post Docs were asked to rank their reasons for participating in outreach on a scale of 1 to 7, where 7 is the most important ranking. The graph displays mean ranking. Error bars reflect the standard error of the mean. Figure 3(b) shows the mean ranking of how often obstacles to participation occurred on a scale of Never (0) to Always (4). The only statistical difference between graduate and undergraduate students is that lack of time was more of a problem for undergraduates than for graduate students.

Participants also ranked the top obstacles to their participation on a scale of 1 to 4, where 4 occurs most often. "Insufficient time" was the only barrier of any note, with a mean rank of 2.2 ± 0.9, as shown in Figure 3b. Lack of time is also the only obstacle for which there is a statistical difference between graduates and undergraduates. It is more of an issue for the latter, probably because their class schedules are more restrictive.

Indeed, when asked the open-ended questions of what they liked least about their involvement in outreach, and separately, if they have any suggestions for improvement of the program, many participants noted the following:

- *Outreach is often scheduled in the morning and mid-day when UNM classes meet so undergraduate students in particular can't participate in K-12 school day events*
- *Outreach is often clustered in bursts: i.e., three per week for two or three weeks instead of spread out throughout the semester*
- *Not enough notice is given before an outreach event, so it is difficult to plan*
- *It would be better to let UNM students sign up for one hour increments instead of requiring them to be at the K-12 school for two or more class periods*

We have modified the program to address these concerns. The Outreach Coordinator spreads events over the semester, provides up to a month's notice of the events, posts them on a calendar and allows students to sign up for one hour increments and for specific duties such as "present the talk" and/or "interact with students during the hands-on activity." As mentioned previously, the website Volunteer Spot helps automate these tasks. Scheduling outreach later in the day is problematic, as APS schools are dismissed as early as 2:30 pm. The Outreach Coordinator tries to divide events evenly between Monday-Wednesday-Fridays and Tuesday-Thursdays. We are exploring the possibility of participating in "family nights," especially at elementary schools..

Another difficulty we have encountered is that some UNM students and post-doctorals are more willing to sign up for outreach events than others, which causes resentment among some frequent participants. To address this problem, the Outreach Coordinator sends reports directly to each PI identifying those students who have not volunteered. We also now integrate an outreach orientation into a regular department seminar for graduate and undergraduate students at the beginning of the term so that all students clearly understand the minimum number of hours (~ 4) they are expected to contribute to outreach each semester. During this orientation, we also train students on how to conduct the outreach activity and provide tips for interacting with younger children.

We have not included assessment attitude and learning data of the K-12 students because these are linked directly to the efficacy of the specific modules we have chosen and would not be relevant to faculty groups developing their own module content.

SUMMARY

We describe our approach for a comprehensive program that vertically integrates outreach from the elementary through the University level. We developed this program as part of a six-year, five-investigator grant targeted at increasing diversity in the engineering student pipeline through biomaterials-related research. The architecture of our approach may be generalized to a wide range of disciplines. Because three of the five principle investigators were tenure track, we structured the program to limit the demands on any one individual, allowing "matured" elements to be laterally delegated to student volunteers. To date, we have involved nearly a hundred UNM students, Post Docs, faculty, and staff in outreach to the community in 169 events. Our program has become a locus for outreach at the Center for Biomedical Engineering and in engineering departments, drawing students, faculty and staff who are searching for outreach opportunities.

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ABSTRACT

The Journal of Materials Education (JME) is an international peer-reviewed professional journal, publishing scholarly articles, review papers, and teaching resources in order to foster communication on subjects related to Materials Education. Submission of original manuscripts is welcomed. This article provides guidelines for authors, using itself as a model. Authors are requested to use these guidelines judiciously in the preparation of manuscripts.

Keywords: *Journal of Materials Education; author instructions; style manual*

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$$xy = \int_{z=0}^{n} \exp(a/b).dz \qquad (1)$$

Tables

Tables should be numbered sequentially, and each Table given a brief caption or title.

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