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# Contribution to the Study of the Rill Density Effects on Soil Erosion: Laboratory Experiments

L. Mouzai, M. Bouhadef

**Abstract**—Rills begin to be generated once overland flow shear capacity overcomes the soil surface resistance. This resistance depends on soil texture, the arrangement of soil particles and on chemical and physical properties. The rill density could affect soil erosion, especially when the distance between the rills (interrill) contributes to the variation of the rill characteristics, and consequently on sediment concentration.

To investigate this point, agricultural sandy soil, a soil tray of  $0.2 \times 1 \times 3 \text{ m}^3$  and a piece of hardwood rectangular in shape, to build up rills, were the base of this work.

The results have shown that small lines have been developed between the rills and the flow acceleration increased in comparison to the flow on the flat surface (interrill). Sediment concentration increased with increasing rill number (density).

**Keywords**—Soil erosion - artificial rainfall - rills - transport capacity - experiments.

## I. INTRODUCTION

**R**ILLS are defined as small intermittent water courses with steep sides, usually a few centimetres deep and, hence, no obstacle to tillage operations. Some studies deal with the experimental interrill soil losses in soils. Torri et al. [1] have shown that surface runoff reaches its maximum power both as detaching and transporting agent, once channeled into rills. This concept was stressed by Morgan [2] when he found that the amount of sediment removed from rills was about 40 times the amount removed from the interrill areas on an  $11^\circ$  sloping sandy soil ([1]). Several other observations are also significant with regard to rill generation (Bryan, [3]). Rainsplash impact was found to have little effect on flow velocity and net drag force; but it always increased transport capacity and wash sediment concentration (Savat, [4]). Killinc and Richardson [5] also found that in extremely thin flows entrainment efficiency increased with rainfall rate. Rainsplash impact is therefore an important factor affecting particle entrainment in sheet flow and transport of particles from rill interflaves into channels.

Some authors preferred to relate rill erosion to hydraulic characteristics such as shear velocity (Govers[6]), Froude number (Govers[6], De Ploey [7], Savat[4]).

A combination of critical Froude number and wash load concentration was proposed by Boon and Savat[8] to identify susceptibility to rilling.

Consequently, the evaluation of sediment concentration, generated by variable rill density under rainfall, is important in soil erosion studies.

Kinnell [9] expresses the interrill erosion by a relation including parameters such as the interrill erodibility, the rainfall intensity and the slope factor.

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To understand clearly this evaluation, the diagram (Fig.1) representing the different relationships between rainfall, soil characteristics and rill erosion is proposed.

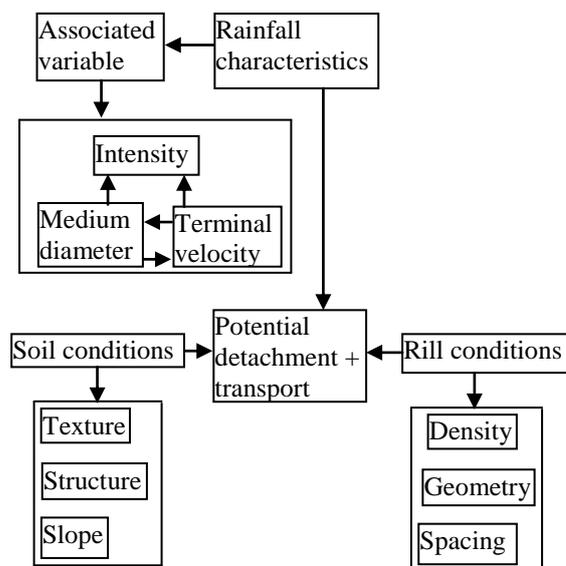


Fig. 1 Soil erosion generated by rill density under various conditions

## II. EQUIPMENT AND METHODS

The simulator chosen is as used by many authors, such as Moussouni et al. [10], Madi et al. [11]; only the shape and sizes were modified. Artificial rainfall is produced using a commercially-available type of nozzle (1/2HH 25 Fulljet). This simulator consisted of 3.5 meters steel tube rigidly mounted in a rectangular carriage which is longer than the flume soil tray, in order to cover the total area of the soil. Two nozzles 1.5m apart were fitted. The carriage, which supported the sprinkler (tube with nozzles), is 3.5 meters above the soil surface and is supported by four bars. Water is centrally supplied by a pump to the sprinkler unit from a tank through a gate valve and pressure gage. The sprinkler is calibrated using plastic cups and rainfall intensity is linked to the pressure gage indication.

The soil tray, which is used in this investigation, is similar to that used by some other authors such as Ballal and Deshpande[12] and Meyer in Bryan et al.[13]. The soil tray is constructed with a plywood bed, supported by a steel frame. One support consisted of two drilled legs, these holes allowing the slope angle of the tray to be adjusted. The tray walls were 20cm high and made of clear plastic. The width is one meter and the length is 3meters. Tray slope is adjustable by a jack at one end, while at the other end is placed a flow collector. The jack is placed in the middle of the top end support between the drilled legs. Once the top end is jacked up, the angle is chosen by choosing the hole

corresponding to the required angle. The slope angle used in this study is  $2.5^\circ$ .

A tank at the top end of the soil tray supplied the soil surface with water to generate overland flow. This tank is controlled with a calibrated inlet tap to vary the rate of water delivery.

In these experiments, the procedure used to measure the rainfall intensity is the simple volumetric method. The rainfall intensities measured are quite high and ranged as 190, 217.20, 239.48 and 337.91 mm/h. The volume drop diameters were 1.32; 1.21; 1.07 and 1.04 mm corresponding to these rainfall intensities respectively. In many tropical countries, intensities of 150 mm/h are experienced regularly. A maximum rate, sustained for only a few minutes, was recorded by Hudson in Africa at 340 mm/h (Hudson[14]). The rainfall intensity used in this investigation is 217.20 mm/h.

To investigate this area, an agricultural sandy soil (32% sand, 38% silt, 28% clay and 1.9% organic matter) is used. This soil is cleaned only of pebbles larger than 20 mm maximum dimension. The tray is filled with soil until the surface is level with the collector rim, and flattened to have an homogeneous surface. The soil is saturated before each run, using a fine rainfall droplets generated by high pressure. The fine droplets have been used to avoid any kind of destruction and to keep the soil natural. This saturation means there is no infiltration, which standardizes the effects of the presence of rainfall intensity.

The rill density represents the number of rills per unit area of the soil surface. To investigate the rill density effects on soil erosion, under rainfall, artificial rills were constructed parallel to the tray length. To built up the rills along piece of hardwood, rectangular in cross-section (2.5 cm by 3 cm), is pushed uniformly into the soil until the top surface is level with the soil surface to produce a rill 3 cm deep and approximately 2.5 cm wide. This operation is repeated for the other rills to obtain uniform rill characteristics. In addition to this, for following runs, the position of the rill is displaced from the previous one in order to represent a similar soil structure for the other runs. Each run is repeated five times. The number of rills used is 1, 2, 3 and 4 rills within the width of the soil tray (1 meter).

The runoff water/sediment mixture is gathered and directed to the reservoir by a collector. The collector is a rectangular tube along the lower edge of the soil tray. It has a steep lateral gradient in order to evacuate the whole volume of water/sediment mixture rapidly. This discharge  $Q$  is measured volumetrically. Samples were taken at the output of the tube collector every minute from the commencement of flow using cylinders of 1000 ml and a stop watch of 0.01 second precision to record the time of collection. The discharge is determined from the rate of water volume  $V$  (1 litre) and the time  $t$ .

To measure the sediment concentrations, each experiment, using the soil tray, is run for five minutes (high rainfall intensity). After each minute, a sample of 1000 ml of runoff is taken. These samples were stirred again and 200 ml of sediment water is taken from each cylinder. These samples of 200 ml were dried in the oven for 24 hours and

the soil residue is used to represent the sediment concentration of the runoff.

### III. RESULTS AND DISCUSSION

To investigate the rill density effects on soil erosion, the rill number is varied from 0 (flat surface) to 4 rills with fixed sizes. The results are presented in Table 1 and the relationship, between sediment concentration and rill density (number), is presented in Fig. 2.

To understand the rill density effects on sediment concentration, the description of the experiments is needed. At the beginning of each run, the rainsplash is the main detaching factor, and the surface roughness is broken down by the raindrop impact. Small lines were developed between the rills, and the acceleration of the flow, inside the rills, increased significantly in comparison to the flow on the flat surface between the rills. The consequence of this acceleration is the high sediment concentration, because, not only are the particles transported by the flow in the lines, but also the rill edge aggregates fall down into the rill by the raindrop impact and the line transport (interrill transport). When the roughness decreased with time, soil compaction started to take place and the heavy aggregates and particles, that the flow in the rills could not transport, blocked the channels and the rill depth decreased. This decrease started from the bottom of the plot which created an approximately flat sheet of flow. In addition to this, in some segments of the rills, the width was extremely large, due to the cutting of the edges by horizontal or oblique flow and the downslope flow of the rills. The bed surface of the rills is always smooth and covered with loose sand particles. Once the rill depth started to decrease, the sediment concentration decreased with time.

TABLE I  
RILL DENSITY EFFECTS ON SOIL EROSION

Rill number	$q$ ( $m^2/s$ ). $10^{-4}$	$Sc$ (g/l)
0	2.02	10.30
1	2.21	13.52
2	2.29	14.22
3	2.26	15.01
4	2.34	16.42

$q$  is overland flow unit discharge generated by rainfall intensity of 270,2 mm/h (high rainfall intensity);  $Sc$  is the mean sediment concentration of five samples taken from the output of the collector during each run. These values are the mean of five runs for each rill number.

The relationship, between sediment concentration and rill density, presented in Fig.2, has shown that the sediment concentration, initially increased sharply, then increased more slowly with increasing rill number. The assessment of soil erosion by the rills is related to the depth and width of the rill. In this study, both dimensions were kept constants. Therefore, the soil erosion depends on the wetted section of the rill and the velocity of the water/sediment mixture flow. Both these factors are related to raindrop splash and interrill transport.

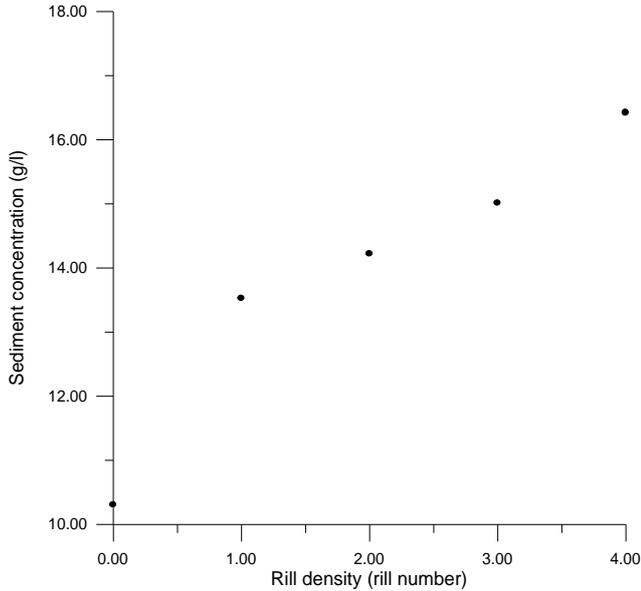


Fig. 2 Relationship between sediment concentration and rill density

The raindrop splash is expressed by the splash distance. As we know from the literature review, the amount of particles splashed from the impact point decreased sharply with distance. Therefore, the splash distance and interrill transport could explain the slow increase of sediment concentration with the rill number. In the case of one rill, more particles are transported to the rill, by the interrill flow, than by rainsplash. In the case of two rills, the particles splashed into the rills increased and the interrill flow distance decreased. This means the velocity of the interrill flow decreased and the dominance of splash became greater.

In the literature review, rills have been investigated in the laboratory and in the field and different results have been found. Govers and Poesen [15] assessed the interrill and rill contributions to total soil loss, from an upland field plot, and concluded that sediment detachment on interrill areas occurs mainly by splash, while interrill wash is the most effective sediment transport agent. Young and Onstad [16] developed laboratory instrumentation to separate the rill and interrill erodibility of soils, and several studies have shown that interrill flow is less effective in transporting large particles than rill flow (Albert et al. [17]; Loch and Donnellan [18], [19]). Bryan [3] reported that the processes and rates of interrill erosion are extremely complex and varied, depending both on extrinsic factors, such as rainfall intensity, raindrop size and the presence or absence of wind influence, and intrinsic factors, such as soil texture, aggregation characteristics, surface roughness, susceptibility to crusting, and the presence and density of organic debris. He added that, in the absence of rainsplash, sheet flow became unstable and incised rills. In this study, the rills were found filled with particles at the end of the runs.

At the beginning of the experimental runs, rainsplash was the main detaching factors, and roughness was broken down by the raindrop impact. Small lines developed between the rills and rate of flow acceleration in the rills increased in comparison to the flow on the flat surface between the rills. The increase of sediment concentration is due not only to the particles transported by the flow in the lines, but also the rill edge aggregates falling down into the rill, due to

raindrop impact and to flow lines transport. The surface roughness decreased with time as the larger aggregates and particles that the flow in the rills cannot transport, blocked the channels, thus decreasing rill depth.

Let us recall some notions already stated in Moussouni et al. [20]. Soil erodibility (symbolized by a K index), which is the susceptibility of the soil to erosion, represents the behavior of the soil in the water environment. This parameter is evaluated by the WEPP (Water Erosion Prediction Project) for several soil types, under the effect of variation in rain intensity and soil slope. The study of the behavior of surface runoff, produced by rainfall, on the soil and its relationship with soil erodibility, better explains the phenomenon of erosion.

In the WEPP erosion model, the interrill erosion surface is expressed as:

$$E = K I^2 S_f \quad (1)$$

where E is the erosion rate of the interrill, S<sub>f</sub> is the slope factor, K is the erodibility and I is the rainfall intensity. The slope factor S<sub>f</sub> is expressed by the relationship:

$$S_f = 1.05 - 0.85 \exp(-4 \sin \phi) \quad (2)$$

where φ is the angle, in degrees, of the slope.

These last two equations have been exploited by several authors (Truman and Bradford [21], Kinnell and Cumings [22], Kinnell [9], [23], [24]).

Since equation (1) ignores the effects of flow rate and infiltration, Kinnell [23] proposes to add the flow discharge to the WEPP model to write it:

$$E = K I q S_f \quad (3)$$

By definition, the runoff sediment concentration is expressed by the equation:

$$C_s = q_t / q \quad (4)$$

where q<sub>t</sub> is the sediment transport capacity (soil weight/surface unit/time).

If L is the length of the eroded surface in the direction of the flow, the relationship between E and q<sub>t</sub> is:

$$q_t = E.L \quad (5)$$

The combination of equations (1)-(5) gives the expression of the erodibility as follows:

$$K = C_s / I.S_f.L \quad (6)$$

From this equation, one can notice that soil erodibility depends on sediment concentration, which itself depends on runoff rate, rainfall intensity, slope and runoff length.

The results representing the hydraulic characteristics of the runoff and rainfall are summarized in the table II below where Re is the Reynolds number. Hydraulic characteristics of runoff and rainfall.

TABLE II  
HYDRAULIC CHARACTERISTICS OF RUNOFF AND RAINFALL

$C_s$ (kg/m <sup>3</sup> )	$I \cdot 10^5$ (m/s)	$K \cdot 10^5$ (kg.s.m <sup>-4</sup> )	Re
12.56	5.28	3.94	182.75
10.31	6.03	2.83	201.25
9.32	6.63	2.33	219.50
8.32	9.38	1.47	255.25

The results in the table show that the flow regime is a laminar regime ( $Re < 500$ ). Runoff, in the presence of the impact of raindrops, appears in a turbulent regime. Once the impact of the drops is reduced, the disturbance "dissolves" and the flow becomes laminar again. Soil roughness can also contribute to runoff disturbance, especially if the runoff is finely lamellar and the soil is reworked agricultural soil.

From these results, it is clear that the susceptibility  $K$  of the soil to erosion decreases with increasing rainfall intensity. This can be explained by the following phenomenon: the increase in rainfall intensity leads to an increase in the depth of the runoff. This depth absorbs the energy from the impact of the drops and reduces the detachment of the particles.

Erodibility decreases with increasing Reynolds number. It should be noted that the susceptibility of the soil to runoff erosion is mainly due to the impact of drops rather than runoff.

#### IV. CONCLUSION

Sediment concentration increased sharply at the start of each run, then declined with increasing rill number. The splash distance and interrill transport could explain the slow increase of sediment concentration with rill number or density.

Soil erodibility can better explain the change in Reynolds number of runoff generated by rainfall on an agricultural soil than other hydraulic parameters.

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# Epidosites of the Loki Crystalline Massif, the Caucasus: Geological Setting, Mineralogy, Petrogeochemistry and Genesis

David Shengelia, Giorgi Chichinadze, Irakli Gamkrelidze, Tamara Tsutsunava, Giorgi Beridze, Irakli Javakhishvili

**Abstract**—The pre-Alpine Loki crystalline massif is exposed in the northern part of the Baiburt-Sevanian terrane. Its area is 1000km<sup>2</sup>. It is represented by metamorphites of greenschist and epidote-amphibolite facies of Paleozoic regional metamorphism and ophiolitic complex of the very low stage of metamorphism. The metamorphites are represented by alumina enriched metapelites -, chloritoid-, phengite-, chlorite-, andalusite and garnet-bearing schists; actinolite-, chlorite-, albite and carbonate bearing schists, graphitic quartzites, marbles, metabasites and also epidosites. Epidosites are of great interest for the authors as these rocks have not been studied yet in Georgia. The ophiolitic complex is built up of weakly metamorphosed gabbros, gabbro-diabases and amphibole-bearing schists. The Upper Devonian quartz diorites and Lower Carboniferous granites play significant role in the make-up of the massif; their formation is connected with the Bretonian and Sudetian orogenies, respectively. The impact of granites over the metamorphites is well expressed. In the contact zone andalusite, cordierite, K-feldspar, biotite, plagioclase, hornblende and garnet occur.

The epidosites are concordant, often well schistose, banded and layered rocks from one centimeter to one meter in thickness. They alternate with mica schists and sometimes associate with metabasites as well. The epidosites are represented by quartz-epidote-bearing and anchimonomineral epidote group minerals-bearing varieties. In any case, the epidote predominates, but clinozoisite and zoisite also occur. Besides the above-mentioned minerals, in the composition of epidosites in various (sometimes significant) amounts chlorite, actinolite, plagioclase, calcite and ore minerals are found. The transformation of epidosites into plagioclase-actinolite schists, sometimes even within one layer takes place. Number of petrogenic elements in the rock varies in the following ranges: SiO<sub>2</sub> - 38-44%, FeO+Fe<sub>2</sub>O<sub>3</sub> - 9-15%, MgO - 6-10%, CaO - 5-18%, Al<sub>2</sub>O<sub>3</sub> - 10-18%, Na<sub>2</sub>O - 0.14-2.22%, K<sub>2</sub>O - 0.026-1.31%.

Several ways of epidosite formation are known: regional metamorphism of sedimentary rocks, contact influence over the limestones and impact of ascending flows of hydrothermal systems over the rocks of ophiolitic series. It should be noted that the regional metamorphism of the crystalline massif is of isochemical nature, and therefore epidosites were forming without the participation of metasomatic processes. This is confirmed by the fact that in the host mica schists the epidote does not appear even in contact with epidositic layers. Therefore, the epidosites of the

Loki crystalline massive are product of the regional metamorphism.

Epidosites were studied in detail geologically, mineralogically and petrographically. The obtained data have been plotted on corresponding diagrams. Reconstruction of rock composition has been produced, according to which most of the primary rocks of epidosites were of sedimentary and volcanogenic-sedimentary origin.

**Keywords**—Caucasus, epidozites, Loki crystalline massif, metamorphism, petrogenesis.

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# Pre-Alpine Allochthonous Metabasites of the Loki Crystalline Massif, Georgia: Geological Setting, Composition and Formation Conditions

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**Abstract**—The Loki crystalline massif is exposed in South Georgia and it is an inlier of the pre-Alpine basement within the northern marginal part of the Baiburt-Sevanian terrane. The massif is represented by autochthonous Late Devonian gneissose quartz diorites, allochthonous pre-Upper Paleozoic overthrust sheets of metasediments and metabasites and by Late Variscan granites crossing all these rocks. The pre-Jurassic age of crystalline rocks is determined by the transgressive bedding of Liassic terrigenous deposits on it and by numerous geochronological determinations. The object of the research was the pre-Alpine metabasites of the allochthonous complex of the Loki crystalline massif, where four overthrust sheets: Sapharlo - Lok-Jandari, Moshevani, Lower Gorastskali and Upper Gorastskali are distinguished. They differ from each other in composition and degree of metamorphism of their constituent rocks, and often in the orientation of the schistosity and plication developed in them. Metabasites are developed to a various extent in all of overthrust sheets, mainly playing a subordinate role, and only the Lower Gorastskali overthrust sheet is entirely composed of weakly metamorphosed basites. The latter has been studied in detail from both petro-mineralogical and petrogeochemical viewpoint, but the study of the basites of the other overthrust sheets were imperfect. For comprehensive investigations of basic rocks of overthrust sheets of the massif the appropriate methodologies were applied: microscopic study of thin sections and petro- and geochemical analyses of the samples. Content of petrogenic elements and rare elements of key samples from pre-Alpine metabasites were determined. Obtained data were plotted on different petrogeochemical diagrams and spidergrams. Correlation between the existing and drawn versions of diagrams was performed. According to the diagrams petrogeochemical characteristics of metabasites of the overthrust sheets of the Loki massif, expressing some differences from each other, correspond to normal alkali, alkali and tholeiitic series. They are disposed in the field of withinplate (WPB) and island-arc tholeiitic (IAT) basalts and very rarely in the field of enriched basalts of mid-oceanic ridges (E-MORB). According to the petrogeochemical features, the metabasites of the Lower Gorastskali overthrust sheet differ from the metabasites of other overthrust sheets of the massif. It is composed only of the basites of the ophiolite complex and covers a transitional part of the second and third layers of the oceanic crust. According to the geological position and the petrological and geochemical characteristics, the basites of the Lower Gorastskali sheet differ sharply from the metabasites of the other overthrust

sheets. The ophiolites, in the form of separate flakes, occur in the Upper Gorastskali and Sapharlo - Lok-Jandari overthrust sheets as well.

**Keywords**—Georgia, Loki crystalline massif, metabasites, petrogeochemistry.

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# The Use of Software and Internet Search Engines to Develop the Encoding and Decoding Skills of a Dyslexic Learner: A Case Study

Rabih Joseph Nabhan

**Abstract**—This case study explores the impact of two major computer software programs *Learn to Speak English* and *Learn English Spelling and Pronunciation*, and some Internet search engines such as Google on mending the decoding and spelling deficiency of Simon X, a dyslexic student. The improvement in decoding and spelling may result in better reading comprehension and composition writing. Some computer programs and Internet materials can help regain the missing awareness and consequently restore his self-confidence and self-esteem. In addition, this study provides a systematic plan comprising a set of activities (four computer programs and Internet materials) which address the problem from the lowest to the highest levels of phoneme and phonological awareness. Four methods of data collection (accounts, observations, published tests, and interviews) create the triangulation to validly and reliably collect data before the plan, during the plan, and after the plan. The data collected are analyzed quantitatively and qualitatively. Sometimes the analysis is either quantitative or qualitative, and some other times a combination of both. Tables and figures are utilized to provide a clear and uncomplicated illustration of some data. The improvement in the decoding, spelling, reading comprehension, and composition writing skills that occurred is proved through the use of authentic materials performed by the student under study. Such materials are a comparison between two sample passages written by the learner before and after the plan, a genuine computer chat conversation, and the scores of the academic year that followed the execution of the plan. Based on these results, the researcher recommends further studies on other Lebanese dyslexic learners using the computer to mend their language problem in order to design and make a most reliable software program that can address this disability more efficiently and successfully.

**Keywords**—Analysis, awareness, dyslexic, software.

## I. INTRODUCTION

**D**YSLEXIA is a common learning disability that exists in most academic institutions. However, most educators do not notice it and are unaware of its nature. According to the International Dyslexia Association Board of Directors [1], dyslexia is a specific learning disability characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. A deficiency in language phonology causes these difficulties leading to ineffective classroom learning. Secondary problems may result. Such problems might be evident in reading comprehension, which can affect growth of vocabulary, problems in writing ability resulting from weakness in spelling

and decoding.

There have always been a variety of methods and techniques to help the dyslexic learner overcome this disability. Most of these methods and techniques have been based on direct psychological procedures as well as on non-academic treatments such as resorting to special schools and institutions for the dyslexics. What is needed here is a method or tool that can help the dyslexics overcome their learning problems without making them feel that they are different from other learners. This tool may be the computer with its software and Internet access.

Dyslexic learners find it difficult to read and comprehend texts and write pieces of composition due to difficulty in reading and spelling. Misreading of words may lead these learners to experience a problem in comprehension and understanding of texts, for “if they could read the words, then they could comprehend the meaning of text” [2] and “poor word recognition diverts resources from the processes that are necessary for comprehension” [3]; furthermore, they misspell words (even the easiest ones) and that leads to poor composition writing. Thus, the solution is mending the roots of this problem, which is the decoding and spelling of words. A lot of techniques are used to help dyslexic learners overcome their problems. For instance, in private institutions for dyslexics, specialists use re-education methods where the student re-learns the alphabet, all sounds, and all the sound combinations, and odd word spellings etc., in addition to using tactile, kinesthetic, visual, and auditory senses simultaneously. However, these learners, especially those who are about to turn into teenagers, feel depressed and miserable for the special care they are shown. Students just need to feel they are learning in an environment or atmosphere where they do not feel inferior to or different from other learners. In addition, like normal learners, they need motivating methods and tools. An effective motivating tool which may help improve the spelling and reading abilities of dyslexic learners is the computer with its software and Internet material. According to [4], there are many highly motivating traditional teaching methods, but such methods are discarded when Computer-assisted Language Learning (CALL) is brought into the teaching process. When computers are used in a learning task, students may stay longer on task and their commitment to learning is increased [4]. Consequently, they achieve more by being more enthusiastic about their lesson. This notion of implementing the computer to create motivation may be applied on dyslexic learners in the same way it is applied on

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non-dyslexic learners.

The following questions arise in this context:

1. How efficient can the computer be on the decoding and spelling of dyslexic learners in home tutoring?
2. How motivating can the computer be for such learners?
3. What software is to be used?
4. Can the Internet be used? How?
5. Is it possible for the dyslexic learner to do self-tutoring using the computer?

## II. REVIEW OF LITERATURE

### A. *Dyslexia - A Learning Disability*

Experts agree that dyslexia is a learning disability that affects language processing. It is not due to inadequate intelligence, lack of motivation, poor instruction, vision or hearing problems, cultural disadvantages, or other extrinsic factors. Rather, it is a genetic neurobiological disorder in which an individual has atypical brain structure and/or function. It runs in families, and there is no medical cure [5], [6]. Reference [6] talks about a research conducted through using magnetic resonance imaging (MRI), which “has produced an unprecedented ability to visualize the human brain with clarity comparable to post-mortem evaluations” [7], to compare the brain structures of dyslexic learners with those of normal learners. The research shows that the rear portion of the brain left hemisphere, which processes language and communication, of the dyslexics is much smaller than that of the normal readers. The researcher adds that these findings have been amplified by Professor Albert Galaburda of Boston, Massachusetts. Through dissection, Dr Albert confirmed that dyslexics had clusters of large cells in the left area of the brain 30% smaller than non-dyslexics of similar IQ. This suggests that dyslexics find difficulty in processing detailed information quickly. This difficulty in quick processing of detailed information results in difficulties in phonological and phoneme awareness. Reference [8] confirms that “children who are slow in their language development of phonology may develop a disorder of reading”. References [9], [10], and [6] add that phonological and phoneme awareness has very strong effect on early reading success because children have to learn what letters stand for. According to [11], weakness in phonological processing can most often hinder early reading and spelling development for both students with or without disabilities but may have a stronger effect on those with a disability. These phonological and phoneme awareness deficits, as [3] argues, “account for a large proportion of the difficulties encountered by dyslexic children and adults”. According to [12], research from around the world assures that the main deficit in specific reading disability is in printed word decoding recognition, caused mainly “by underlying deficits in analytic language skills of phoneme awareness (reflecting on sounds within a syllable) and phonological decoding (translating print to sound)”. This decoding recognition, according to [13], is an important part of reading. Reference [13] adds that to read well “the reader needs two kinds of information. One is knowledge of the spelling-sound

correspondences of the language, or what we have called the orthographic cipher”. This cipher of English is very complex because the English letters do not stand in one-to-one correspondence with their phonemes. The English alphabet has 26 letters, whereas the spoken English contains over 36 phonemes. Therefore, some letters represent more than one phoneme, or some phonemes must be represented by the combination of letters [13]. Consequently, all learners need this cipher to spell and read well, particularly the dyslexics who have more difficulty (as mentioned earlier in this chapter, due to the malformation of some part of their brain) in dealing with this cipher which is represented in phoneme and phonological awareness.

On the human level, the main problem is the misconceptions of many educators regarding dyslexia, which results in wrong or no treatment for those with this learning disability. In a study by [5], which included university faculty as well as undergraduate and graduate students preparing to become administrators, counselors, elementary general education teachers, secondary general education teachers, speech therapists, and special education teachers, to study their beliefs regarding dyslexia, it was found that the majority of those included in the study had significant misconceptions about dyslexia. Reference [14] states that sometimes schools and local boards of education do not regard dyslexia as an entity because they do not have the resources to meet the needs of students with dyslexia. Thus, they refer to ways which frustrate the students, and instead of mending the problem, they worsen it. Reference [6] says:

The consequences of simple shouting at dyslexic people, of failing to understand their problems and what it feels like to have them, are simply to compound their frustration. Even worse, it is to increase their very large potential for low self-esteem and even humiliation (p. 9).

Reference [6] adds, “The worst problem any dyslexic has to face is not reading, writing or even spelling, but lack of understanding”, which so often takes an extreme form out of teachers’ ignorance and results in frustration for both teachers and learners alike. Consequently, [5] adds that as a result of school experiences, a lot of pupils grow with social and emotional problems such as low self-esteem, disappointment, powerlessness, shame, and hopelessness. Thus, students with dyslexia are more frustrated than other slow learners because they have more cognitive-awareness of their difficulties. The impact of such incidents on dyslexics’ self-esteem and self-confidence can be more damaging than dyslexia itself. Reference [15] says that students with dyslexia have less self-esteem, self-confidence and expect to fail in chores. She adds that teachers have a vital role in fostering their students’ self-esteem, but they can also reduce this self-esteem when they ignore or disregard this learning disability as a major deficit in their students. Teachers should remember that although dyslexia is “invisible,” it is a very real disability [16], and as [6] states, its “denial has potential for enormous harm”.

### B. *The Computer - A Tool to Teach Reading and Spelling*

The second section of this chapter emphasizes the computer

and its importance in teaching language, particularly reading and spelling. Computer technology has become a major technological influence on our lives in the last two decades. More and more of its unique features are found every day and it is not surprising that the field of education has been widely affected by this tool. Reference [17] states:

Technological literacy- meaning computer skills and the ability to use computers and other technology to improve learning, productivity, and performance- has become as fundamental to a person's ability to navigate through society as traditional skills like reading, writing, and arithmetic.

It has turned out that this technology, through computer assisted language learning (CALL), has brought significant benefits to teachers and students alike. Reference [18] says, "It is a most appropriate aid for language learning that has interaction as its goal". It creates all kinds of interaction in the language learning such as student's interaction in all language skills and fields through the use of different kinds of software and Internet material.

Learning is not the same with computers, which have revolutionized the way language is learned. Reference [19] believes that "From the home and the classroom to the market or workplace, computers are reshaping the environments in which language is learned, produced, and practiced". One of the best features of computers is that it can create motivation, which is essential in teaching and learning. Reference [20] believes that motivation is related to one of the most basic parts of the human mind and it can determine success or failure in any situation. He adds that without motivation, even the brightest students fail to attain any stated or targeted language objective. This aspect of motivation may be created by using the computer on any learners, with or without a learning disability. Reference [21] notes that the computer has a beneficial effect on learner motivation; they add that "It offers privacy, which relieves learners from the fear of being ridiculed for their mistakes by their classmates". It creates learning equality between all learners and makes low achievers feel they are high achievers.

Reference [4] argues that using the computer can be very motivating to low achieving students because many low achievers in language can be high achievers in computer technology and thus their self-esteem and self-confidence return to them in a way that has never been thought of. She adds that through the use of word processing, students who do poorly at writing and have little interest in this aspect of their work improve their self-esteem, their commitment and perseverance in learning tasks. Reference [22] says that "word processors, for example, facilitate the invention, revision, and editing processes of writing, allowing quick, easy reshaping of text". In a study by [23] of 144 pupils' opinions about how ICT (information and communication technology) contributed to their school work, over 70% of the pupils believed that it helped them to achieve a better quality of work.

Computers are very useful machines. You can set out and present your work very well. You can type up essays and other information. When a mistake is made you can

go back and delete the mistake or amend your document unlike typewriters you have to use Tippex.

(Secondary female pupil – aged 13)

Another good feature of the computer is that it can help improve the reading and spelling abilities of language learners. For example, there is a program in which learners read stories on the computer gaining speech feedback and decoding assistance for any difficult words. Whenever learners ask for help on a word by targeting it with a mouse, the program highlights and subsequently pronounces it, either as a whole, in syllables, or in sub syllable segments [12]. In addition, [12] developed a program that can help learners improve their spelling. The program is called *Spello*, in which the computer pronounces a word to spell. In the interactive speech version, the speech synthesizer pronounces any attempt typed in by students, so they can compare the sounds of spelling patterns as they change letters, as in "bak" to "bake". They can also request spelling feedback to learn which of their letters are in the correct word, and which are correctly placed [12]. Several computer programs have been designed and implemented with young readers to ameliorate or prevent literacy difficulties. *Writing to Read*, for example, was designed to improve the reading and writing performance of young students in kindergarten and first grade [24]. Therefore, with the abundance of educational programs, teaching of spelling and reading skills can be done through the computer.

### C. The Computer- A Tool to Help Dyslexic Learners

The third part of this review deals with implementing the computer in helping dyslexic learners improve their reading and spelling abilities. Reference [25] confirms that using technology with students of special needs is not just encouraged, but it is a law now. He adds that students with special needs and learning disabilities such as dyslexia must be provided equal access to education programs supported by technology, particularly the computer. With the advent of this technology and greater access to computers, well designed CAT (Computer-Assisted Teaching) with a reading emphasis may help students with learning disabilities practice their language better [26]. Educators and researchers such as [27] have predicted a positive impact of computers on students with learning disabilities. Simon X, a grade 8 student with a learning disability, specifically dyslexia, said:

"I prefer using the computer for learning spelling because it's more motivating and funnier than the normal way with the use of paper and pens. Also, the computer has taken a part in my life that makes it even easier and more effective than the paper and pens way. "

Reference [27] states that "computers have the capacity to deliver motivating, carefully monitored, individualized, and speed-oriented practice in concentrations far beyond those available in traditional instructional format". What is needed (as mentioned previously) is a method to teach the dyslexics in the same way as ordinary learners are taught.

Reference [28] remark that when working with students with special needs, it must be clear that they can benefit from the computer technology the same as other pupils. They give

an example of how the computer can be used with dyslexic students. A voice-activated computer is needed to allow pupils to input written work. The educational outcome of this is “Pupil independence and increased phonological awareness – improved reading and spelling skills” [28]. They also talk about specific software addressed to learners with disabilities such as dyslexia. Three such software programs are *Full Phase*, *Talking Pendown*, and *Keystone*, which give the learners the chance “to speak into a microphone and the computer ‘writes’ what it ‘thinks’ they have said”. Another program particular for the dyslexics is *Easyread*, a system for teaching reading that is based on colors. The way this software works makes it easy for dyslexic pupils to learn pronunciation. Adding to these programs is *Oxford Reading Tree*, which helps students to improve in reading and spelling. The student can read and reread and also point to individual words in order to have them repeated. Reference [28] adds that the internet can be useful for students with special needs who have problems with reading and writing. Such children can be motivated through the use of email pen-pals in other schools and different parts of the world.

As quoted by [12], phoneme awareness “is the major cause of problems in phonological decoding. Yet research suggests that they can be remedied with methods specifically designed to address them”. Thus, they have conducted a lot of research on dyslexic learners using computer-supported phonological awareness training. They have developed and studied computer-based remediation focusing specifically on dealing with deficits such as dyslexia. They have used in their studies the talking computer to provide “a powerful remedial tool by providing speech feedback for difficult words while students read stories of interest to them”. This method of “talking computer” is the focus of my choice of software that is used in treating the dyslexic student under study. The “talking computer method” plays an essential role in the progress of the dyslexic because he finds himself relieved from the stress imposed due to his dyslexic state when exchanging information, questions and opinions in the presence of another person. This method is a way of exchange of information, and the dyslexic’s anxiety is diminished to a certain extent that his response to the “talking computer” becomes highly interactive. This will lead him/her to cooperate more effectively and more comfortably than when exchanging information with another person. The progress in overcoming his/her learning difficulties becomes very acceptable and flexible in order to attain a certain level of confidence which paves the way for him/her to move forward on the right track. Therefore, the more confident the dyslexic is, the better his/her advancement in facing learning difficulties becomes. It turns out to be easier to reach its objective i.e. overcoming the learning disability.

To sum up, dyslexia is a deficit that is not so easy to mend, and there have been a variety of methods and techniques to help dyslexic learners. The computer is a tool of unique features that may help learners in all areas of language learning, particularly reading and spelling. This tool may be useful with dyslexic students to help them improve their

reading (decoding) and spelling skills.

### III. METHODOLOGY

The case study is the style of the educational research used in this project. As reported by [29], a case study is the study of a specific instance in action which is designed to reach a more general principle. Thus, the case study style could be used in this research since as [29] state that the single instance in action

“provides a unique example of real people in real situations, enabling readers to understand ideas more clearly than simply presenting them with abstract theories or principles”.

In addition to this, a case study can provide the reader with an in-depth view of the situation and how it is investigated. As [30] say:

Case studies enable the investigator to ground the observations and concepts with which she or he works. The detailed and rich data offered by the well-crafted case study permit the analyst to develop a solid empirical basis for specific concepts and generalizations.

Reference [31] supports this view, saying

“one of the pluses of using case study methodology and methods is that an in-depth situation/individual, and so on, can be explored fully”.

To confirm this, as cited in [29], Sturman argues that the remarkable feature of case studies is that the human system has wholeness in them rather than being “a loose connection of traits” and this necessitates a deep examination.

The study undertaken in this research is how the computer with its software and Internet materials can help a dyslexic learner overcome the problem of spelling and reading. Therefore, this study, with all its parts, is conducted on a dyslexic student to see if the computer can help him, and consequently, other dyslexic learners to improve in spelling and reading.

In this case study, the researcher took an in-depth look at the participant in order to investigate all the aspects of his situation and try to find a solution for his problem.

However, the author of this study had little control over events since it was processed smoothly with no direct interference in events except when using the computer to apply the research plan. The teaching and learning process was carried on naturally and without controlling the track and progress of events taking place during the study. This aspect of the research in which the researcher has little control over events, according to [32], gives value to the case study approach by letting situations move on naturally without any outer intervention.

Besides all this, in a case study, a learner “might suddenly pass a single comment that indicates complete frustration”, which is very important to overlook and consider with value because this significant instance can give the researcher an important insight into the events and people engaged in the study [29].

#### IV. PARTICIPANT

A case study research can be applied on one or more participants. According to [29],

“the case study researcher typically observes the characteristics of an individual unit - a child, a clique, a school or a community”.

Reference [33] says that the unit of study in a case study “could even be one person, e.g. a student in a school or college”. References [31]-[34] confirm that a case study can focus on individual participants. Reference [35] asserts that the main focus of a case study can be on the “singular, the individual”. References [36]-[38] conducted case studies on single participants.

##### A. Character and Conditions

The student in this case study research is Simon X, a 13-year-old, right-handed Lebanese boy who attends the International School of Choueifat in the southeast region of Lebanon. Simon is a quiet and reserved boy. He is usually expressionless and his face is hard to read. In an educational evaluation report done on January 4, 2002, Ahamd Oueini, Ed.D., an educational specialist, certified by the City of New York, reported that Simon was evaluated due to the difficulties he faced with his reading and spelling skills. According to the doctor’s report, Simon’s case “is the fruit of a complicated pregnancy and delivery.” Dr. Oueini’s report added that Simon, who was born in Saudi Arabia, was a LBW (low birth weight) baby. Moreover, the subject of this study “reached his developmental milestones with a noticeable delay in most skills. Besides language delay, he reportedly was a stutterer.” However, Simon’s mother stated that his defects are currently controlled.

The third of four children, Simon’s learning problems turned out to be plain when he started grade school. Once more Dr. Oueini mentioned that Simon has been examined by a number of specialists for a range of purposes, “including psychological, psycho-educational, behavioral, and speech and language”. He has been diagnosed as having ADHD and specific learning disability (dyslexia). As a result, he has been put on psycho stimulant medication (Concerta), the improved version of Ritalin with longer-lasting effects. “He is reportedly responding favorably to the medication.” The report also mentions that Simon is currently “weakest in Arabic, but generally coping with the other subjects. He receives significant support at school, but he is still not up to par.”

##### B. The Learning Environment

Simon X, as we mentioned earlier, attends the International School of Choueifat, a member of the SABIS international education program. The school follows the objective type of exams, and since Simon’s cognitive abilities are average, fortunately, the subjects learning disability does not affect his performance in most subjects except the English language exams of spelling, reading, and of course, writing skills. The ambiance of his home is calm in general. His mother is very supportive and understanding to his case and tries to help her son by offering encouragement. She has always assigned a

private teacher to help him in all school subjects. However, she has not been able to find a special tutor who can help her son overcome his disability in reading, spelling, and writing (which is mainly affected by the numerous misspelled words). Simon does not receive any remark or criticism about his dyslexia problem except from his younger brother, who sometimes brags about his ability which excels that of his brother in the matters, as we said, of spelling and reading. In addition, Simon’s self-confidence and self-esteem are below average, as with most dyslexic cases. He feels weak no matter how he tries and he believes that it is all due to his “rotten brain”.

#### V. THE PLAN

Four hours of tutoring is given each week, two hours on Wednesdays and two hours on Saturdays. For each two hour session, a spelling and/or reading activity of about 30 minutes is given using the computer. As previously mentioned, what a dyslexic learner mainly needs is an increase in his/her phoneme and phonological awareness which, according to [11], is to have a general understanding at different levels. This is illustrated in Fig. 1 [11].

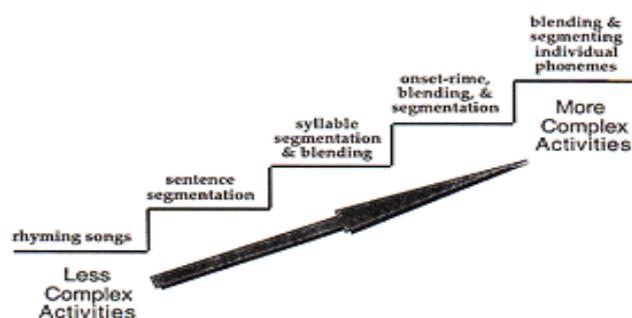


Fig. 1 A continuum of complexity of phonological awareness activities

Accordingly, three educational software programs which focus on this awareness are utilized: *Learn to Speak English*, *Learn English Spelling and Pronunciation*, and *Learn English Reading and Grammar*. In addition, the Internet is used for extra material and lessons related to reading and spelling, and as supplementary practice exercises for *Learn to Speak English*, which includes a part that can be practiced on the Net.

As reported earlier, Simon’s auditory processing is high average, so my focus is on using software that provides speech feedback and decoding assistance for any difficult word. *Learn to Speak English* is used to teach reading and spelling as its content integrates reading with spelling. This software, though its title refers to the speaking skill, can be used to teach reading since speaking is integrated with listening and most of its activities include listening to words, conversations, and documentaries with the ability to read them simultaneously. In other words, Simon listens and reads the words concurrently. To teach reading, the software works on letter sounds and letter combinations which is also appropriate for spelling. In

addition to this software, *Learn English Reading and Grammar* functions as supplementary software to teach reading. *Learn English Spelling and Pronunciation* is another program utilized specifically for spelling. For self-tutoring, the programs are left with Simon so that he practices alone as they are user-friendly.

To practice spelling, *Microsoft Word* is used to write words since this software can show that the word is misspelled and Simon can retry writing the word until it is spelled correctly or he can use the spell checker. For self-tutoring, the researcher recorded the words on *Windows Media Player* to which Simon can refer to at a later time, so as to listen to the words and practice spelling them. The software programs are to help Simon reach the normality level of decoding and spelling based on the PA-EFL program, which is outlined as follows:

#### **Pre-Phonics Level**

- A. Same-different
- B. Inclusion-exclusion
- C. Deletion and substitution

#### **Level One: Alphabet**

- A. Sound-letter-keyword recitation
- B. Cues for sound-letter associations

#### **Level Two: Segmentation**

- A. Alliteration
- B. Blending of CV's and CVC's (C = consonant, V = vowel)
- C. Rhyming with CVC's

#### **Level Three: Short Vowels**

- A. Multisensory experience
- B. Discrimination in CVC minimal pairs

#### **Level Four: Long Vowels and Diphthongs**

- A. Silent E
- B. Double vowel combinations
- C. R colored vowels
- D. Irregular combinations (e.g., ough)

#### **Level Five: Multisyllabic Sequences (2 and 3 syllables)**

#### **Level Six: Consonant Clusters (2 and 3 consonants)**

## VI. DATA COLLECTION

Reference [39] confirms that triangulation or “convergence of methods” is an effective technique to validate collection of data. Triangulation is the use of two or more methods of data collection in the study of a certain aspect of human behaviour. Reference [29] reports that “triangulation can be a useful technique where a researcher is engaged in case study, a particular example of complex phenomena”, and [35] assures that triangulation is obviously a significant feature in the process of analysis and interpretation. In addition to all this, [40] state that a number of authors believe that triangulation has an important role in the validation of findings. Therefore, to ensure validity of collecting data, four methods of collection are utilized: tests, observation, interviews, and accounts.

### **Data Analysis**

According to [30], a case study is a “deep, multifaceted investigation”, using the qualitative methods, but some case studies have made use of both qualitative and quantitative

methods. Reference [41] confirms this by saying that the variety of perspectives and units of analysis which can achieve a complete case understanding requires the integration of both qualitative and quantitative methods. Reference [42] adds to this notion that “each of the two approaches provides a distinctive kind of evidence and used together they can offer a powerful resource to inform and illuminate policy and practice”. Reference [34] mentions that qualitative and quantitative analysis “both may be utilized in the same study”. In addition, the results of qualitative research can be measured to some extent in quantitative data, too. Thus, the data in this case study are analysed both qualitatively and quantitatively in three different ways. In the first, the qualitative data study precedes the quantitative one to help in devising areas of questioning for statistical study. In the second, the qualitative analysis is alongside the statistical enquiry to examine both the number and the nature of the same phenomenon. In the third, the qualitative analysis functions as a follow-up to statistical enquiry when there are instances where statistical enquiries present findings that need further explanations or where more detail or depth about a phenomenon is needed.

#### *A. Qualitative Analysis*

According to [34], for a qualitative analysis, a researcher can use a variety of methods and data collection strategies for “a holistic, in-depth understanding” of the study. Therefore, the data assembled in the methods of collection will be discerned, examined, and interpreted. Thus, data analysis includes the coding of the data and the production of verbal synthesis. The aim of this kind of analysis is a complete, verbose, detailed description of what has been explored and discovered and to present the findings as clearly, coherently and attractively as possible.

#### *B. Quantitative Analysis*

For quantitative analysis, features are classified, counted and presented in numbers to show differences and changes. According to [33], “data analysis requires the person to be painstaking, thorough, systematic and meticulous. It also requires a researcher to be ‘true to the data’ and to make a faithful representation of the data collected, especially when presenting it and publishing it”. Thus numbers and statistics can be straightforward, factual, faithful, and direct to the point.

To conclude, the data in accounts and observation as well as in the published tests will be analyzed qualitatively and quantitatively, whereas the focus of analysis in the interviews will be qualitative because, as [34] argues, the unstructured informal interviews are a good instrument to collect and analyze data qualitatively rather than quantitatively. Therefore, all the input variables will be analysed, as we said, qualitatively and quantitatively to produce output focal variables which provide goal achievement, new understanding, and truthful knowledge of this case study.

## VII. RESULTS AND DISCUSSION

### *A. Comparison between Grade 7 and Grade 8*

As we concluded in phase two, Simon’s disability has

changed into ability, and thus altering him into an ordinary learner. Fig. 2 draws a comparison between Simon's grade 7 and grade 8 performances to show how he developed. In this figure, the final averages of both classes are utilized in term 3 to show the total achievements of each class.

Simon started and ended grade 7 very poorly in the spelling skill. Continuing into grade 8, Simon started very poorly; however, he improved in term 2 and ended term 3 with a relatively good score of 10.32/20 in the final exam. The final average of this class, as shown in Fig. 2, is below average due to the very poor score of term 1 (3.20/20). In spite of this, the final average of grade 8 (7.37/20) is still much better than the final average of grade 7 (4.73/20).

As to reading/decoding, Simon ended grade 7 with an average of 10.09/20, whereas he ended grade 8 with an average of 15.44/20. The progress is apparent in this skill between one class and another.

Concerning the reading comprehension skill, Simon ended grade 7 with a score of 10.60/20, while he ended grade 8 with 11.59/20. The difference is slight, but it is worth considering the difficult comprehension final exam given at the end of grade 8, which was confirmed in the interview with Mr. Tiliani (Fourth interview, phase 2).

Simon ended grade 7 with a final average of 11.63/20 in composition writing, while grade 8 was ended with 11.31/20. However, as mentioned earlier, the composition scores of grade 7 cannot be reliable because Simon's composition writing assignments were done with the help of the private tutor, corrected by Simon's teacher at school and then a score was given. To confirm this, we notice in Fig. 2 that the composition scores of grade 8 term 1 and term 2 were below average. In other words, the passing scores of term 1 and term 2 of grade 7 were unreasonable and thus not constructed on a

good basis.

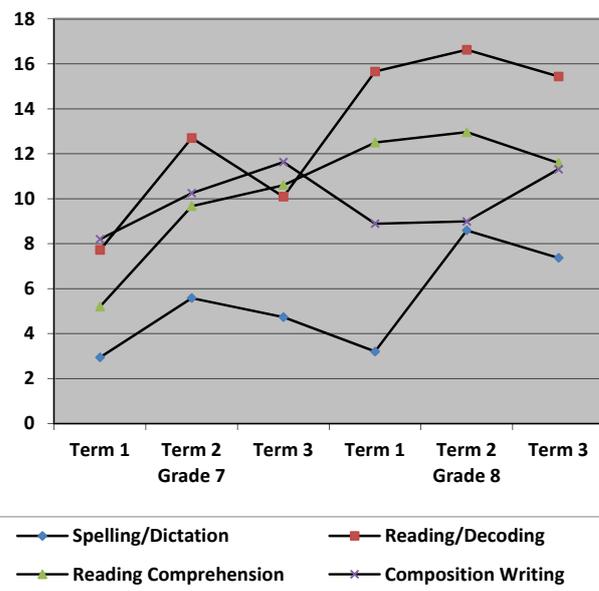


Fig. 2 Comparison between Simon's achievements grade 7 and grade 8 of spelling/dictation, reading/decoding, reading comprehension, and composition writing

*B. Writing Samples before and after the Plan*

To show the development in the spelling skill and its effect on composition writing, two samples of Simon's writing will be presented. The first is a paragraph written one week before starting the plan (Fig. 3), whereas the second was written one week after ending the plan (Fig. 4).

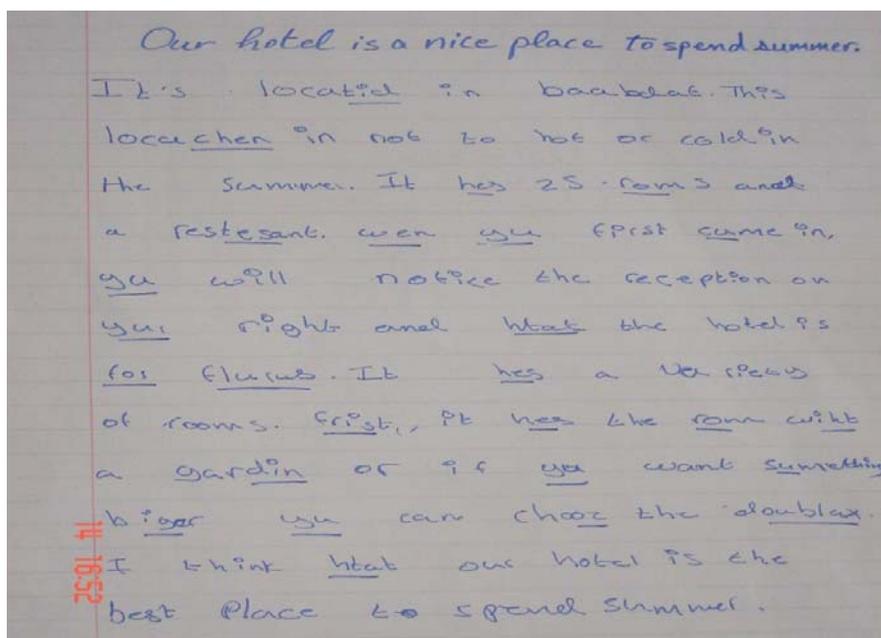


Fig. 3 Simon's paragraph writing before the implementation of the plan

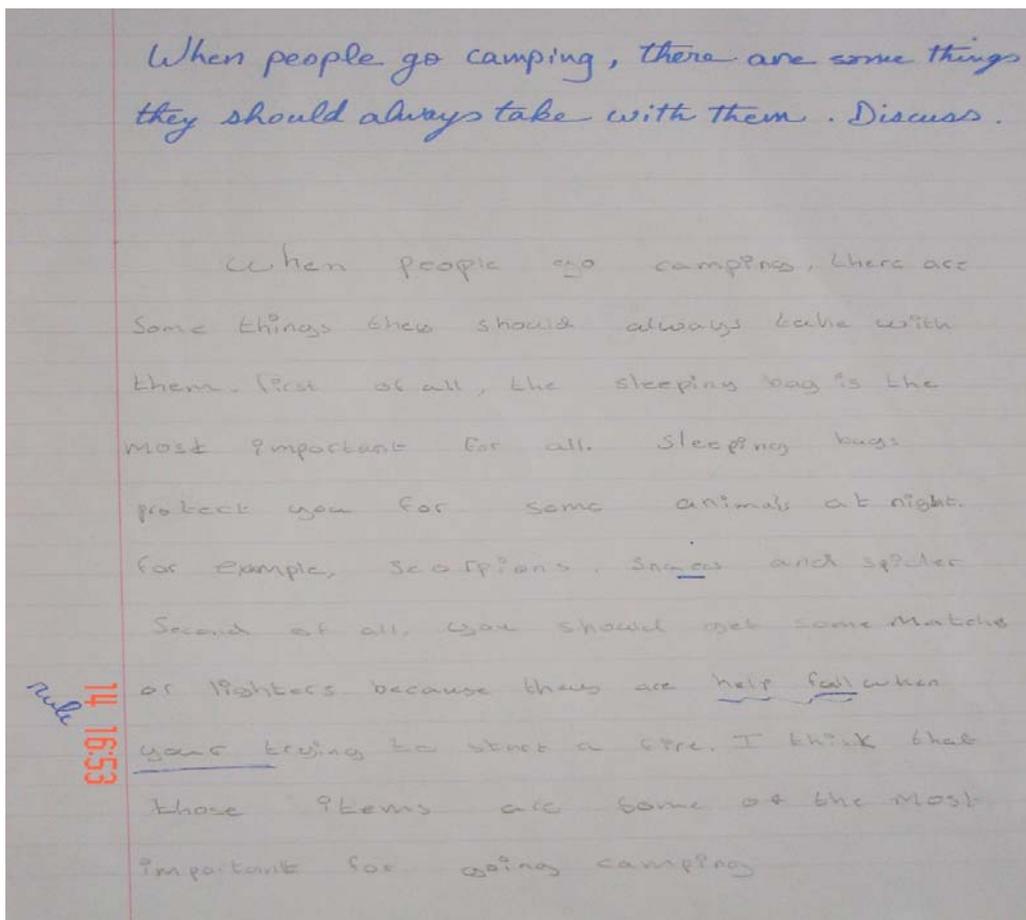


Fig. 4 Simon’s paragraph writing after the implementation of the plan

The first sample provides us with a clear idea about Simon’s quantity and quality of spelling errors. The number of mistakes is 26 varying from consonant sounds like ‘chooz’ (choose), ‘fos’ (for), and ‘restesant’ (restaurant), vowel sounds like ‘locatid’ (located), ‘cume’ (come), ‘hes’ (has), ‘sumething’ (something), and ‘gardin’ (garden), consonant combinations like ‘htat’ (that), ‘wen’ (when), and ‘wiht’ (with), vowel combinations like ‘rom’ (room), ‘restesant’ (restaurant), ‘yur’ (your), and ‘yu’ (you), letter strings like ‘flurus’ (flowers), ‘locachen’ (location), and ‘frist’ (first), silent letters like ‘wen’ (when), and suffixes like ‘biger’ (bigger). On the other hand, the second sample presents a good idea about the development that occurred during the plan and its result on Simon’s phoneme and phonological awareness. The number of mistakes is only three. There is one error in the consonant sound ‘snaces’ (snakes), one in suffix ‘help full’ (helpful), and one in homophone ‘your’ (you’re). The subject no longer writes ‘you’ as ‘yu’, ‘that’ as ‘htat’, ‘with’ as ‘with’, ‘frist’ as ‘frist’, ‘for’ as ‘fos’, ‘when’ as ‘wen’, and ‘some’ as ‘sume’. In addition to these examples, the sounds and combinations of other words seem much better. For example, he writes a lot of words correctly like ‘people’, ‘important’, ‘should’ (silent letters), ‘night’ (silent letters), ‘example’, and ‘think’, in addition to many others.

### Recent Chat Conversation Sample

In addition to the two samples, the following is a recent messenger conversation between Simon and me, asking him for a favor. “Survival of the fittest” is Simon’s nickname on the messenger chat window.

“Rabih” says:  
**hi Simon**  
 Survival of the fittest says:  
 hey sir  
 Survival of the fittest says:  
 how are yoy  
 Survival of the fittest says:  
 you\*\*\*\*  
 “Rabih” says:  
**good**  
 “Rabih” says:  
**u?**  
 Survival of the fittest says:  
**good**  
 “Rabih” says:  
**is ur mom there?**  
 Survival of the fittest says:  
 no she in baabdat  
 “Rabih” says:  
**do u know if she got me the grades?**  
 Survival of the fittest says:  
 mmmm..... i think she does but im not sure wait a  
 sec. so ill call her

“Rabih” says:  
**thank you so much**  
 Survival of the fittest says:  
 she called the school they told to come and get them  
 tom.  
 “Rabih” says:  
**do all ur grades appear on the school website?**  
 Survival of the fittest says:  
 no i dunno  
 “Rabih” says:  
**Simon can i ASK U FOR A FAVOUR?**  
 Survival of the fittest says:  
 sure  
 “Rabih” says:  
**can ask ur mom now if i can take ur grades from  
 Baadat tomorrow evening?**  
 “Rabih” says:  
**can she do me this favour?**  
 Survival of the fittest says:  
 okay wait a sec.  
 Survival of the fittest says:  
 she said when she gets the grades she ll call you  
 “Rabih” says:  
**ok**  
 “Rabih” says:  
**tell her thanks**  
 Survival of the fittest says:  
 okay  
 “Rabih” says:  
**and a lot of thanks to u for helping me**  
 Survival of the fittest says:  
 sure thing  
 “Rabih” says:  
**ok Simon**  
 “Rabih” says:  
**see u**  
 “Rabih” says:  
**bye for now**  
 Survival of the fittest says:  
 alright c u  
 Survival of the fittest says:  
 bye

The conversation also presents a vivid idea about how Simon’s spelling skill improved. His writing of correctly spelled words even appears in the chat window, where most people (the author of this paper included), in order to save time, use nonstandard words and abbreviations to convey meaning. Other than the informal chat language, you can hardly find a spelling error.

### C. Grade 9 Scores

To confirm that Simon’s language competency in the four under-study skills was established on a good and correct basis in grade 8, his grade 9 class scores of reading comprehension and composition writing are presented to prove this fact. Table 1 presents the scores (decoding and spelling skills do not have separate scores in this class, so they do not appear in the table). It is important to note that Simon attended the grade 9 IP (International Program) which is a rather difficult program.

For the first time in years, the reading comprehension and composition writing scores are all successful. The reading comprehension scores of term 1, term 2, and term 3 are 10.38/20, 12.46/20, and 11.70/20, respectively. The

composition writing scores of the three terms are 10.50/20, 11.25/20, and 10.55/20, respectively. Even if they are not so high, they are considered good results for two reasons, the first of which is that Simon attended, as we said, a difficult international program, and the second is that they are unwavering and based on steady scores.

TABLE I  
 READING COMPREHENSION AND COMPOSITION WRITING SCORES OF SIMON’S  
 GRADE 9 IP

	Term 1	Term 2	Term 3
			<b>Final average</b>
Comprehension	10.38	12.46	11.70
Composition	10.50	11.25	10.55

### D. Results of Phase 3

Phase 3 practically demonstrates the considerable progress that Simon did during grade 8 academic year. The comparison between the scores of grade 7 and grade 8 classes provides us with results that show the big change in this student who is capable now of performing in the language in the same as ordinary students and even better in some skills. The two writing samples append to the scores and prove the considerable development in spelling and its effect on composition writing. The chat conversation also presents a different Simon, who is capable of writing correctly in an environment where everyone is tempted to write informally using nonstandard language. In addition to all this evidence, the scores of grade 9 substantiate that improvement really occurred, for all the results in reading comprehension and composition writing are passing scores that are constant the entire year to show steadiness in Simon’s level in the researched skills.

This phase can answer research question 1, question 3, question 4, and question 5, and further confirms question 2, which was answered in phase 2. The computer has proved to be very efficient on the dyslexic learner subject of this study, whose problem is not a weakness but a disability. The results of the plan, in which the personal computer was utilized, show a significant improvement in Simon, who suffered from not only lack of phoneme and phonological awareness but also low self-confidence and self-esteem. This in-home tutoring tool has helped him acquire the missing awareness and regain his confidence and esteem.

The positive effect of the computer was established through a plan prepared to address the dyslexic deficit in this student who had to learn and practice the phonology of the language through a set of activities specially made to address this problem. The activities made use of four software programs specifically designed to work on pronunciation and spelling skills by starting from the lowest level of the language (consonants and vowels) to the highest (homophones, words with suffixes). The learner started with single consonant and vowel sounds, continued with combinations of vowels and combinations of sounds, and then moved into whole words and additional parts such as suffixes. In addition, the programs integrate pronunciation with spelling as each complements the other. They also contain the sound feature which is important

for the dyslexic student in this study, whose auditory processing is high above average.

The Internet was very effective in this study because it functioned as a catalyst to create motivation and a provider of a lot of supplementary exercises to many activities. Simon did a lot of practice and preparations using the processor alone and without the presence of the researcher.

Further practice on a lot of activities was done through self-tutoring using the computer software and the Internet. Simon was very active and eager to utilize the computer by repeating some activities and downloading items of interest to the available activities such as the list of homophones. Therefore, the results of the study can conclude that some types of computer software like *Learn English Spelling and Pronunciation* and *Microsoft Word*, in addition to Internet search engines like Google, may help in improving the reading and spelling skills of dyslexic learners in private home tutoring and self-tutoring, thus confirming the statement of the hypothesis that has been tested.

### VIII. CONCLUSION

Reference [11] states that lack of phonemic and phonological awareness can be an obstacle for spelling and reading development for all learners, in particular the dyslexics. However, according to [12] the problem of phonemic and phonological awareness can be remedied with methods specifically designed to deal with them. Simon X is a dyslexic learner who has a deficiency in this awareness. The method employed to address his problem is computer software and Internet materials which through a series of activities mend the defect. Some types of computer software like *Learn English Spelling and Pronunciation* and *Microsoft Word*, as well as Internet search engines like Google, can help in improving the reading and spelling skills of dyslexic learners in private home tutoring and self-tutoring.

The software utilized in this study is based on the 'talking computer' technique which, according to [12], is a powerful tool to mend this disability. The three utilized programs *Learn to Speak English*, *Learn English Spelling and Pronunciation*, and *Learn English Reading and Grammar* contain the sound recognition technology, voice recording and playback, and automatic text reading. A plan which contains a series of activities using these programs is established to fix the problem. The implementation of the plan proved to be successful and Simon could develop his language from a low to an ordinary achiever.

The computer and its software addressed Simon's problem directly and resulted in language improvement. At first, this tool functioned extrinsically and motivated him to work as he was good at such technology. When he started to have the language awareness and his language developed, he became intrinsically motivated and worked willingly to establish more phonemic and phonological awareness. Consequently, his self-confidence and self-esteem also developed, for according to [15], dyslexic learners have less self-confidence and self-esteem, and thus they always anticipate failure. However, this confidence and esteem can be regained through more

motivation which "can determine success or failure" [20]. This motivation can be created by the computer which can help restore this missing self-confidence and self-esteem, according to [4]. Simon suffered from low confidence and esteem. Nevertheless, the computer helped him restore these two qualities needed for success. He became very enthusiastic to work during the plan and he was even motivated to complete extra work by himself.

Simon's considerable improvement backs up [12], [23], [25]-[28] notion that the computer is a powerful tool to mend the dyslexic deficiency.

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# A Genre-Based Approach to the Teaching of Pronunciation

Marden Silva, Danielle Guerra

**Abstract**—Some studies have indicated that pronunciation teaching hasn't been paid enough attention by teachers regarding EFL contexts. In particular, segmental and suprasegmental features through genre-based approach may be an opportunity on how to integrate pronunciation into a more meaningful learning practice. Therefore, the aim of this project was to carry out a survey on some aspects related to English pronunciation that Brazilian students consider more difficult to learn, thus enabling the discussion of strategies that can facilitate the development of oral skills in English classes by integrating the teaching of phonetic-phonological aspects into the genre-based approach. Notions of intelligibility, fluency and accuracy were proposed by some authors as an ideal didactic sequence. According to their proposals, basic learners should be exposed to activities focused on the notion of intelligibility as well as intermediate students to the notion of fluency, and finally more advanced ones to accuracy practices. In order to test this hypothesis, data collection was conducted during three high school English classes at Federal Center for Technological Education of Minas Gerais (CEFET-MG), in Brazil, through questionnaires and didactic activities, which were recorded and transcribed for further analysis. The genre debate was chosen to facilitate the oral expression of the participants in a freer way, making them answering questions and giving their opinion about a previously selected topic. The findings indicated that basic students demonstrated more difficulty with aspects of English pronunciation than the others. Many of the intelligibility aspects analyzed had to be listened more than once for a better understanding. For intermediate students, the speeches recorded were considerably easier to understand, but nevertheless they found it more difficult to pronounce the words fluently, often interrupting their speech to think about what they were going to say and how they would talk. Lastly, more advanced learners seemed to express their ideas more fluently, but still subtle errors related to accuracy were perceptible in speech, thereby confirming the proposed hypothesis. It was also seen that using genre-based approach to promote oral communication in English classes might be a relevant method, considering the socio-communicative function inherent in the suggested approach.

**Keywords**—EFL, genre-based approach, oral skills, pronunciation.

## I. INTRODUCTION

From a study carried out in the master's thesis of the supervisor of this project [1], it was possible to observe that, although the different language skills were addressed in the classroom, the study of pronunciation in particular did not get the same attention [2][3]. In general, it can be observed that the phonetic-phonological aspects do not play their proper role in teaching, since in most of the available teaching materials (basically textbooks), pronunciation is not addressed in an integrated way to the other linguistic

abilities, which is believed to impair the use of the foreign language competently.

In order to integrate foreign language (FL) pronunciation teaching with the other language skills (written comprehension, written production, oral comprehension and oral production), it is important to stick to a contextualized and meaningful pedagogical practice, according to the Proposed Foreign Language Curriculum in High School [4], so that the students can have real experiences of interaction in the classroom as well. In order for such an objective to be achieved, pronunciation teaching based on the presuppositions of the theory of textual genres was chosen, a theory defended by Bakhtin [5], who understands language as a social, historical and ideological phenomenon, in which the utterance is understood as a unit of verbal communication, provided that there is alternation among the interlocutors with a specific purpose. It is from Bakhtin's thinking that Dolz and Schneuwly [6] use genres as instruments for teaching. This same proposal is suggested by the official texts when encouraging the use of diverse genres in the teaching of foreign language for High School [7]. This research proposal is also in line with the work currently carried out at the Coordination of Foreign Languages at CEFET-MG, Campus I, on the implementation of a new Political Pedagogical Project through a genre approach for teaching English as a Foreign Language (EFL).

## II. MOTIVATION AND JUSTIFICATION

In addition to the development of the written modality, one of the main objectives for teaching EFL in regular secondary education is to improve students' perceptual and oral skills so that they can deal with practical situations to use the target language [4]. Since these skills also contribute to the development of the communicative competence, it is understood that the teaching of pronunciation must be taken into account from the initial years of contact of the student with the English language, which in the case of CEFET-MG begins in the 1st high school classes. Focusing specifically on the teaching and learning of aspects related to pronunciation, we sought to describe some important underlying concepts, as well as to prepare a proposal that fits that institution.

Literature on second language acquisition suggests that, with the strengthening of the Communicative Approach, between the 1970s and 1980s, the formal correction of structures gave way to this new method of teaching and, by its influence, any material that addressed the segmental components, strongly practiced in the past, would be discarded [8].

It is considered, however, in agreement with other authors, that once the idea that the different approaches must be complementary and non-substitutive stands out, antagonistic positions used in the field of linguistics can be treated in relative terms [9], which, in turn, will enable the development of more pedagogical practices. With this, the

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issue of teaching oral skills - focusing on aspects of pronunciation - integrated to the approach of genres can be positive in relation to their development.

For this objective to be achieved, the work of both the segmental and the suprasegmental aspects of the target language seems to be relevant<sup>1</sup>, as also suggests the Curricular Proposal for Foreign Language in Secondary Education [4]. In this way, the students become able to construct meaning based on such FL sound marks. Still according to the proposal, and in line with the ideas of Jenkins [10] and Crystal [11], these aspects should focus on the acquisition of an intelligible pronunciation, in contrast to the focus given to the pronunciation of the native speaker.

However, it is important that the transference of sound aspects of the mother tongue (which differ from the FL) does not impair the intelligibility of the communication, as well as sounds of English considered difficult for Brazilian speakers are taken into account by the teacher in the teaching and learning process [12]; [13].

### III. OBJECTIVES

The general objective of this project is to analyze the students' perceptions regarding the development of oral skills from the genre-based approach.

The specific objectives are:

- i) to carry out a survey of aspects related to the pronunciation of the English language that Brazilian speakers consider most difficult in EFL context; and
- ii) to discuss the role of textual genres in the development of English pronunciation.

### IV. THEORETICAL FRAMEWORK

During the first months of work, some texts from several theorists of the area were read and analyzed to provide a better interpretation of the objectives of the project. These texts focused on understanding the major problems currently found in the teaching of FL pronunciation worldwide, analyzing students' greatest difficulties. The texts also analyzed how pronunciation was taught in schools over the years, with research that proved (or not) the effectiveness of a number of methods and theories. These files were also an efficient source of references to be used in the practical part of this project, demonstrating effective ways of collecting and analyzing information.

Bearing in mind the focus of this project, which is to integrate the teaching of phonetic-phonological aspects to a practice focused on the precepts of the textual genres approach for the development of oral skills, we try to present some considerations about works related to pronunciation teaching and the teaching of L2 through this approach that have already been conducted. However, it is important to point out that there is still little (or even no) research addressing the teaching of L2 pronunciation integrated with the approach at issue.

The approach through textual genres was basically rooted in the presuppositions of the socio-interactionist bias, which, in turn, has its roots in Vygotsky's thinking. The main idea that this part defends refers to the presence of a third mediating element between humans and the world in the

process of language acquisition, be it another individual or the learner itself [14]. The socio-interactionist theory gave support to the fact that Vygotsky's thought about human cognition in the process of learning was transferred to a new theoretical, sociocultural line of thought [15], which supports us in the execution of this project.

In general, sociocultural theory has as one of its roots the understanding that the human mind is mediated by artifacts, whether symbolic or material, that is, the individual does not act directly in the physical world in which they live without the use of tools that play the role of mediators of the construction of mental activities. All this construction takes place under specific historical and cultural conditions.

Swain, Kinnear, and Steinman [16] define sociocultural theory as the means by which human beings think through the creation and use of mediation tools. Another premise that underlies this line of thought concerns the importance of interaction in the learning process, since it is through this that the learner can co-construct their knowledge with the participation of more linguistically competent individuals. In the classroom context, for example, there is the possibility of the participation of students and teachers in collaborative tasks with specific purposes. In the accomplishment of these tasks, by the interaction, zones of proximal development (ZPD) are constructed, what fosters the learning [17]. It is understood as ZPD the difference between what the learner can perform without the aid of the other and what he can achieve with the cooperation of a more competent pair. Scaffolding actions are preponderant in the social mediation task that takes place in the ZPD.

Under the sociocultural aspect, it is remarkable that social practices have been mediated by new technologies, in an increasingly multimodal world. Therefore, it is important that we think of the integration of students in these contexts, since the lessons developed with these instruments seem to have great potential to become more interesting and meaningful. Chapelle [18] states that the contact of students with authentic content through the Internet is a source of input full of new information that, when understandable, can aid in the acquisition process of the target language. Still in the same rationale about the use of new technologies, Brown [19] states that they can motivate students in discovering new meanings through the vocabulary employed in the classroom.

Based on a view of sociointeraccional language, the teaching objects we propose to adopt for the development of oral skills are the different textual genres found in nowadays society. The approach to teaching through genres allows students to be prepared for the social practices with which they have to interact daily. From the theorization that genres are relatively stable types of utterances and the medium through which we communicate [5], it is important to know how to take advantage of this relative stability so that students can recognize the various texts and interpret them according to their characteristics during the learning process.

In addition, the various genres can be presented to students through these new teaching tools, making classes closer to personal interests and, consequently, creating more motivating strategies for the development of language skills and encouraging new ways of re-signification of content.

#### 4.1 A genre-based approach in FL

Some studies have demonstrated the effectiveness of working with different genres in the context of FL classroom [20]-[22]. Bambirra's work [20], [14], for example, sought to investigate the teaching of writing skills in English as FL among elementary school students. The results indicated that there was a significant improvement in the students' perception of texts and their production, as well as the creation of more effective texts for the achievement of the various social functions to which they were subjected. Along the same line of reasoning, Dias [21] presents a general analysis of the approach through textual genres in foreign language textbooks and suggests the use of such an approach for teaching and learning practices of the language. Pinto [22] similarly suggests how textual genres can be inserted in the school context and also points out how they can contribute to the reception and production of information that is meaningful to learners.

#### 4.2 Pennington's proposal

From Pennington's proposal [3], the aims of pronunciation teaching should be based, in order of priority, on the three notions that follow: intelligibility, fluency, and accuracy. The term intelligibility has been widely discussed by scholars such as Jenkins [10] who elaborated in her seminal book *English as a Lingua Franca*, a list of phonetic-phonological aspects considered more relevant to teaching and which, according to the author, should be prioritized for communication to happen among non-native speakers of L2, since these are currently the majority [11]. Making communication intelligible means that the learner can manage to be understood, which, according to the author, is not a simple task in the initial years of learning. Consequently, this notion should be emphasized from the first contact of the students with the foreign language, since it can contribute to the formation of their linguistic competence. In addition, the notion of fluency, that is, the ability that the learner begins to demonstrate in relation to the articulation of the sounds of the FL must be subsequent to that of the intelligibility in the practice of teaching, proper place for the development of this ability. Finally, the notion of accuracy should be the last stage to be focused on the didactic process, since in this stage the focus is on the phonetic accuracy of the sounds previously worked out, which consequently requires a more advanced level of proficiency on the part of the student.

Therefore, considering the need to present the different notions of pronunciation to the student in order to meet the proposal defended by Pennington [3], it was chosen to integrate such notions to the use of textual genres that surround the different social spheres in which students are inserted.

### V. METHODOLOGY

Being the focus of this research the work by means of genres tied to the segmental and suprasegmental aspects of FL, Pennington's proposal [3] will be directed to each series specifically. For collection purposes, we have chosen the debate genre, to facilitate the oral expression of the participants freely, and also the recording of the speeches for later analysis of the aspects suggested by the author. First-grade students focused on the notion of intelligibility,

since they can theoretically be considered less proficient in the language. Second-grade students were specifically analyzed within the notion of fluency, understanding that they are, to a certain extent, more competent than the students in the previous series and can already be understood in a given communicational situation. On the other hand, Third-grade students shifted our attention to the aspects of accuracy of the sounds of the FL, since they are expected to be linguistically more competent than the members of the other previous series.

#### 5.1 Questionnaire elaboration

The questionnaire that was produced for application went through several versions until it could be approved and applied to the students who were participating in the project. Each question sought to clarify possible doubts about the general difficulties of students in teaching pronunciation in English. Its final version had seven questions, six of them of multiple choice, and the last requesting a justification. The objectives of each of the questions were:

Question 1: It aimed to clarify the students' view of their own abilities regarding English pronunciation. In this way, it was possible to know the level of each of the analyzed series.

Question 2: It sought to calculate an average of the greatest difficulties of such students when speaking English. The alternatives rely on sounds of the language that are commonly the object of complaints from students who are not yet used to the phonetics of the English language.

Question 3: When analyzing the answers to this question, it was possible to have a sense of how much the teaching of pronunciation is considered important and effectively applied in the English language schools and colleges of the region, and possibly the country. It is important to remember that because it is a technical school, the students are well distributed and probably attended different educational institutions in the past, which enriches the research.

Question 4: A kind of complement for the last question, it aimed to analyze more deeply how much the teaching of pronunciation is applied in the diverse educational institutions of the region, when asking the students about the phonetic alphabet. This aspect of the English language is often not part of the high school curriculum, however important it might be.

Question 5: It aimed to investigate students' knowledge of the technical terms (intelligibility, fluency and accuracy) that are the roots of this project.

Question 6: In one of the texts studied at the beginning of the project, the author said that many students did not feel safe enough to actually practice their second language learning because of the lack of pronunciation knowledge. In this question we tried to investigate the relevance of this information, when seeking to know the insecurities of the students in a more direct way.

Question 7: Finally, it sought to know the opinion of the students about the need to teach pronunciation in institutions. A justification was requested for a better analysis of the opinions and points of view of the students.

### 5.2 Questionnaire Application

The application of the survey occurred during three 50-minute classes for three classes of different grades. First, second and third grade students should individually answer the questions proposed. Each class had approximately 20 students who did not demonstrate difficulties to perform the activity. Most of the doubts, duly clarified by the applicators, were in relation to technical terms and difficulties in interpreting the questions.

### 5.3 The activity on the genre debate

After the analysis of the questionnaires applied, several discussions were held between the supervisors to decide what would be the best textual genre option to be applied in the classes as a way of responding to the project questions.

Considering that the discussion is a way to provide a greater oral interaction between individuals, we came to the conclusion that the debate would be the ideal textual genre to be used in this project.

During a 50-minute class, one for each grade, an activity that would require the student's oral interaction with their classmates was applied. The activity used was called "Hot Air Balloon" (see Appendix), through which everyone in the classroom would be in a hot air balloon about to fall; so that everyone could be saved, two individuals would have to be thrown out of the balloon, for it was overweight. The students would have to present a short speech that would justify why they deserved to stay alive and the result would be announced by the teacher at the end of the lesson. As a way of collecting material for analysis, each of the students who set out to present had their speech recorded. From the recordings we were able to identify which/if the aspects proposed by Pennington [3] were or not confirmed.

## VI. DISCUSSION OF RESULTS

### 6.1 Questionnaire Analysis

First, all the surveys were collected so they could be scanned using Google Forms production tool, which allows online creation and analysis of surveys for free. In this way, the evaluation of the students' responses was made considerably easier. The questionnaires were separated by students' grades and scanned in different forms for a better interpretation of the data according to the theory proposed in the theoretical framework. With the major use of graphics, it was possible to attain a broad view of the way each grade sees and understands the English language, as well as the pronunciation teaching and improvement.

Most first-grade students considered their own pronunciation of English as bad, having a greater difficulty with the phonetics of words like "girl" and "pearl" that have the "rl" consonants in a row. They claimed to have had very little approach to pronunciation teaching during the time they attended English classes. Thus, they had never seen or only heard of phonetics and its function in the language. Moreover, the great majority also did not know the terms fluency, accuracy and intelligibility nor the way those were applied in the pronunciation of the second language. The lack of confidence in speaking English to others was also

extremely common, mostly because of the fear of misreading words and lack of vocabulary. Regardless of all this, 95% of them considered it essential that pronunciation be addressed in teaching, mainly because of its importance during a real-life dialogue.

Second-grade students, on average, claimed to have a regular pronunciation, with greater difficulty in words with 'rl' consonants, as well as the first-grade students. Unlike the previous class, they said they had seen pronunciation teaching in the same proportion of vocabulary and grammar. In addition, a greater share of students showed to have knowledge of phonetic symbols, although most of them continue to have only heard of it. Like the first-graders, most of them did not know the difference between intelligibility, accuracy and fluency, but they considered the main reason not to speak English with someone else the lack of vocabulary, and not the fear of misunderstanding the words. In general, 90% considered the teaching of pronunciation essential.

Finally, the third-grade students were more divided as to the answers. Although the majority considered their own pronunciation bad, the graph was well distributed among the other options. There were two alternatives that tied, so they have the same difficulty with words with 'rl' consonants and with words beginning with 'th'. An equal number of people also claimed to have studied next to nothing regarding the teaching of pronunciation during English classes, and to have studied vocabulary and grammar in the same proportion. They were also divided between the shallow knowledge of phonetic symbols and the "I have already heard about it". Like the other grades, however, most students claimed not to know how to differentiate intelligibility from accuracy and fluency. They would not speak English with another person for fear of misunderstanding and considered this area essential to be taught in English courses.

### 6.2 Application of the debate activities

The audios containing the speeches given by the students of each grade in the debate were analyzed regarding the pronunciation and elocution of each student, so that it was possible to successfully relate the theories used in this research with the practice.

First-grade students demonstrated more difficulty with aspects of English pronunciation than other grades. Many of the speeches had to be listened to more than once for a good understanding, thus confirming that intelligibility would be the aspect that should be addressed in first-grade classes. In the second-grade class, the speeches were considerably easier to understand, but nevertheless students found it more difficult to pronounce the words 'fluently', often interrupting their speech to think of what they were going to say next and how they would say it, stuttering at many moments. Therefore, fluency was applied as the aspect that should be approached in second grade classes. Finally, most third-graders presented their speeches and ideas almost fluently, but still subtle errors were perceptible in speech, which would validate focus on the accuracy aspect of third-grade classes.

## VII. CONCLUSION

By triangulating the data collected in the questionnaire and the recordings of the application of the textual genre in

the classroom, we conclude that the ideas proposed by Pennington [3] apply to the context analyzed in this project.

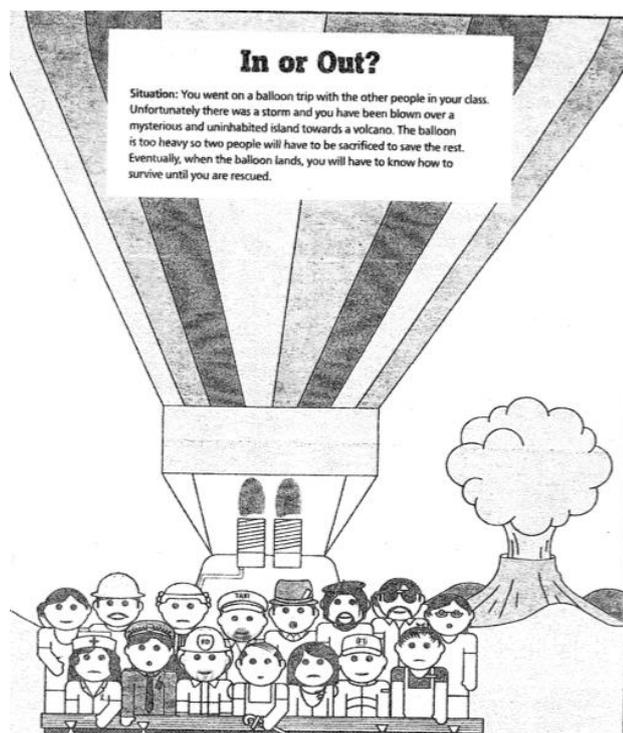
The first-grade students, although specifying the difficulty with the sounds of the "r" consonants, have demonstrated problems in the oral expression of their discourses in general, often being misunderstood by their colleagues and mentors. The second-graders' speeches were understandable. However, problems in the fluency of sentences and in the pronunciation of words were evident. It was possible to notice some difficulty in the formulation and pronunciation of more extensive sentences. Finally, the recordings of the third-grade students have shown a greater mastery of the aspects of pronunciation, if viewed under a general scope. However, there have been simple accuracy problems that could go unnoticed, as they are students of a more advanced class.

Regardless of what was said in Question 2 of the questionnaire, the errors were not limited to just a phonetic sound. More complicated words, which have unfamiliar pronunciation to the native speakers of the Portuguese language, were the ones that the students have found most difficulty with.

It is possible to state that Pennington's [3] hypotheses may be significant for the teaching of pronunciation through textual genres, since it encompasses such notions at several levels without disregarding the socio-communicative function of the language. The debate allowed for more interaction between the students and the teacher, so learners were not bored or disheartened to speak English. In addition, it encourages conversation close to the standards of a real dialogue currently, giving students the chance to learn to speak the English language so that they can be understood by native speakers.

With the results of this research project, teachers of the area and other researchers will be able to create new strategies of learning of pronunciation together with the use of diverse textual genres.

#### APPENDIX



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# The Impact of Language Anxiety on EFL Learners' Proficiency: Case Study of University of Jeddah

Saleh Mohammad Alqahtani

**Abstract**—Foreign language Anxiety has been found to be a key issue in learning English as foreign language in the classroom. This study investigated the impact of foreign language anxiety on Saudi EFL learners' proficiency in the classroom. A total of 197 respondents had participated in the study, comprising of 96 male and 101 female, who enrolled in preparatory year , first year, second year, and fourth year of English language department at the University of Jeddah. Two instruments were used to answer the study questions. The Foreign Language Classroom Anxiety Scale (FLCAS) was used to identify the levels of foreign language (FL) anxiety for Saudi learners. Moreover, an International English Language Testing System (IELTS) test was used as an objective measure of the learners' English language proficiency. The data were analyzed using descriptive analyses, t-test, one-way Anova, correlation, and regression analysis. The findings revealed that Saudi EFL learners' experience a level of anxiety in the classroom, and there is a significant differences between the course levels in their level of language anxiety. Moreover, it is also found that female students are less anxious in learning English as a foreign language than male students. The results show that foreign language anxiety and English proficiency are negatively related to each other. Furthermore, the study revealed that there were significant differences between Saudi learners in language use anxiety, while there were no significant differences in language class anxiety. The study suggested that teachers should employ a diversity of designed techniques to encourage the environment of the classroom in order to control learners' FLA, which in turns will improve their EFL proficiency.

**Keywords**—Foreign Language anxiety (FLA), Language use anxiety, Language class anxiety, gender, L2 proficiency.

# Analyzing Political Cartoons in Arabic-Language Media after Trump's Jerusalem Move: A Multimodal Discourse Perspective

Inas Hussein

**Abstract**—Communication in the modern world is increasingly becoming multimodal due to globalization and the digital space we live in which have remarkably affected how people communicate. Accordingly, Multimodal Discourse Analysis (MDA) is an emerging paradigm in discourse studies with the underlying assumption that other semiotic resources such as images, colours, scientific symbolism, gestures, actions, music and sound, etc. combine with language in order to communicate meaning. One of the effective multimodal media that combines both verbal and non-verbal elements to create meaning is political cartoons. Furthermore, since political and social issues are mirrored in political cartoons, these are regarded as potential objects of discourse analysis since they not only reflect the thoughts of the public but they also have the power to influence them. The aim of this paper is to analyze some selected cartoons on the recognition of Jerusalem as Israel's capital by the American President, Donald Trump, adopting a multimodal approach. More specifically, the present research examines how the various semiotic tools and resources utilized by the cartoonists function in projecting the intended meaning. Ten political cartoons, among a surge of editorial cartoons highlighted by the Anti-Defamation League (ADL) - an international Jewish non-governmental organization based in the United States - as publications in different Arabic-language newspapers in Egypt, Saudi Arabia, UAE, Oman, Iran and UK, were purposively selected for semiotic analysis. These editorial cartoons, all published during 6<sup>th</sup>–18<sup>th</sup> December 2017, invariably suggest one theme: Jewish and Israeli domination of the United States. The data were analyzed using the framework of Visual Social Semiotics. In accordance with this methodological framework, the selected visual compositions were analyzed in terms of three aspects of meaning: representational, interactive and compositional. In analyzing the selected cartoons, an interpretative approach is being adopted. This approach prioritizes depth to breadth and enables insightful analyses of the chosen cartoons. The findings of the study reveal that semiotic resources are key elements of political cartoons due to the inherent political communication they convey. It is proved that adequate interpretation of the three aspects of meaning is a prerequisite for understanding the intended meaning of political cartoons. It is recommended that further research should be conducted to provide more insightful analyses of political cartoons from a multimodal perspective.

**Keywords**—Multimodal discourse analysis, multimodal text, political cartoons, visual modality.

## I. INTRODUCTION

**I**N a short speech delivered from the White House on 6<sup>th</sup> December 2017, the US President, Donald Trump, challenged worldwide warnings and declared that arrangements would be made to move the US embassy from

Tel Aviv to Jerusalem but no schedule for the relocation was given by him. Officials, however, predicted that this process will take at least three years. "I have determined that it is time to officially recognize Jerusalem as the capital of Israel," Trump said. "While previous presidents have made this a major campaign promise, they failed to deliver. Today, I am delivering . . . My announcement today marks the beginning of a new approach to the conflict between Israel and the Palestinians," Trump added. Whereas the US President's announcement was hailed by the Israeli Prime Minister, Benjamin Netanyahu, and by leaders in different areas across the Israeli political spectrum, it provoked condemnation from the US allies and a furious reaction from the Palestinian leaders and the Muslim world. That resulted in violent demonstrations in the West Bank and on the Gaza Strip's border with Israel.

In the wake of the declaration of the US President, Donald Trump, recognizing Jerusalem as the capital of Israel, there was a flow of anti-Semitic cartoons in Arabic-language media. The ADL, which is an international Jewish non-governmental organization based in the United States, declared that this issue had prompted a surge of "editorial cartoons suggesting Jewish and Israeli domination of the United States." The ADL highlighted cartoons from Arabic-language publications in Egypt, Saudi Arabia, UAE, Oman, Iran and UK. They ranged from portraying the Israeli Prime Minister, Benjamin Netanyahu, pulling the arm of an American personality who is blindfolded while the two of them are raising a wand shaped like the Star of David to portraying the US President, Donald Trump, as a circus elephant attempting to balance the globe on its trunk, thus obeying the commands of the Israeli trainer. Other images depicted Trump driving off a cliff in a car having the Star of David as a mark on it. Other cartoons portrayed the Israeli flag on top of Uncle Sam's hat while throwing it away showing a Jewish skullcap, and a Jewish personality giving a thumbs-up while Trump is declaring Jerusalem as Israel's capital.

The aim of this paper is to analyze some of the cartoons that highlight the condemnation of the Arab World of Trump's recognition of Jerusalem as Israel's capital. The framework of Visual Social Semiotics, as explained by [1], is being adopted in the present study. Adopting the grammar of visual design as a framework, we illustrate the different aspects of meaning (representational, interactive and compositional) communicated by these visual compositions. The research is an attempt to answer the following research question:

1. How are the various semiotic tools employed by the cartoonists function in realizing some particular

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functions: representational meaning, interactive meaning and compositional meaning?

The paper is structured as follows: It starts with a theoretical background about MDA and a characterization of the genre of political cartooning; then, it briefly portrays some of the previous studies related to a multimodal analysis of political cartoons; next, the methodological framework adopted in the study is presented. This is followed by a detailed analysis of each of the political cartoons selected for the present study in terms of three aspects of meaning: representational, interactive and compositional. Finally, conclusions and suggestions for future research are presented.

## II. THEORETICAL BACKGROUND

### A. MDA

Communication in the modern world is increasingly becoming multimodal in different contexts as text producers frequently draw upon a wide range of semiotic resources for constructing and conveying meaning. One major reason of this new change is globalization and the digital space we live in which have remarkably impacted the way people communicate. Another major reason is that verbal and non-verbal language cannot be separated [2]. Therefore, MDA is relatively recent paradigm in discourse studies where the analysis of language is combined with the analysis of other semiotic resources such as images, gestures, music, sound, colours, actions, etc. for interpreting meaning [3]. Multimodal discourse creates an "integrative meaning" by employing two or more semiotic resources including language, image, video and sound that makes traditional discourse analysis which is restricted to language far from being comprehensive. Halliday's Systemic Functional Grammar (SFG) provides a theoretical framework for MDA [4]. Researchers in this area seek to identify the influence of mode on meaning within a given context focusing on the interaction between multiple semiotic systems. MDA is essentially concerned with the analysis of such semiotic resources and the semantic expansions resulting from the combination of 'semiotic choices' in various multicultural occurrences. A central area of research in MDA studies is the inter-semiotic relation that stems from the interaction of semiotic choices which is known as inter-semiosis [5].

'Visual modality' is one key component of this theory and is primarily concerned with the extent to which an image is judged as either being 'realistic' or being classified as a 'fantasy' or 'caricature'. According to [6], the growing interest in visuality as an area of scholarly research dates back to the 1980s and 1990s "when a number of authors who had been working in linguistics began to realize that meaning is generally communicated not only through language but also through other semiotic modes" (p.6). Scholars in visual analysis argue that images can be analyzed in the same way words are analyzed using theories of language analysis such as Systemic Functional Linguistics [2].

According to [1], the term 'modality' is a linguistic one which refers to "the value or credibility of statements about the world" (p. 155). The authors further argue that modality is 'interpersonal' rather than 'ideational' since it does not

usually express 'absolute truth' or 'falsehood'; rather, it produces 'shared truths' that readers or viewers believe in. In terms of visual modality, visuals can portray people, places or things as though they are real. However, modality judgements are 'social' since they depend on what is regarded as real in the social group to which the representation is directed. According to [7], modality results from:

... the degree to which certain means of pictorial expressions (colour, representational detail, depth, total shades, etc.) are used. Each of these dimensions can be seen as a scale running from the absence of any rendition of detail to maximal representation of details or from the absence of any rendition of depth to maximally deep perspective (p. 256).

Reality is basically related to the frequency of such factors in an image. This means that the more they are prevalent, the more realistic the image would be whereas the less they appear, the more abstract it would be. However, modality depends largely on the context. It follows that this theory is suitable for the analysis of the selected colourful cartoons.

For the study of visual communication, [8] adopts a linguistic approach suggesting that there are two separate levels of visual signification: denotation and connotation. Where the level of denotation corresponds to the literal meaning of an image, the level of connotation corresponds to the symbolic or ideological meaning of an image. Kress & van Leeuwen are pioneers in the analysis of printed texts. In analyzing texts, they adopt a multimodal approach where semiotic modes that accompany language or through which language is realized are included. In fact, social semioticians generally believe that the visual mode is able to express many of the complex meanings as verbal language, though in different forms. These researchers assert that the visual mode has a kind of 'grammar' which determines how visual elements combine into a meaningful whole [9]. As a matter of fact, [1] hypothesizes that "in a literate culture the visual means of communication are rational expressions of cultural meanings, amenable to rational accounts and analysis". Therefore, the problem we face is that "literate cultures have systematically suppressed means of analysis of the visual forms of representation, so that there is not, at the moment, an established theoretical framework within which visual forms of representation can be discussed." (p.22). According to [1], images are "structured messages, amenable to constituent analysis" (p.24).

A close look at the literature on visual communication reveals that visuals prove to be effective in reinforcing the details given in oral language and even provide additional details to oral communication. The theorized effects of visual images are 'mnemonic power' which means that they can be remembered in their general details; their ability to be 'icons', i.e. they can serve as exemplars of certain issues or events; their 'aesthetic impact'; their emotional power, i.e. their ability to create an emotional reaction such as sympathy or rage inside us; and finally, their significant 'political power' which refers to their ability to alter popular beliefs and further affect the policy of the government [2]. p.4.

Such positive effects of visual images justify the

increasing popularity of the visual medium in projecting meaning in modern times. In fact, the use of visuals as a mode of communication has gained much significance in modern communication. More specifically, these effects explain the growing relationship between politics and visuality in contemporary times. For instance, politicians resort to the mnemonic power of the visual so that their political followers would retain the general details of the information about their political ideologies, plans and vision. Generally speaking, visuality is an essential aspect of political expression. Politicians all over the world usually employ visual resources for their popularization prior to elections and similarly, visual images are used in media representations of politicians, their attitudes to the public or the effects of their actions on the public. This is due to the fact that text producers believe that visual images have the ability to provoke deeper feelings in people than verbal language [2]. In addition, editors of newspapers and newsmagazines rely on this mode of communication to voice their thoughts and messages on important political issues. Therefore, through the use of sarcastic political cartoons, editors ensure that messages are conveyed and enriched. The job of a cartoonist is to attack a certain phenomenon through the convention of satire. Political cartooning is a visual medium that engages the audience and helps them to understand the political, social and economic scene in the country and the world [5].

### *B. Political Cartooning*

#### *1) Nature and Significance of Political Cartoons*

A political cartoon is "a satirical comment, usually humorous...about a political person, event, institution or idea, and reflecting the cartoonist's own values or opinions on that issue" [10], p. 4. Thus, political cartoons most commonly address a current political issue or event, a social trend or a famous personality in a way that presents a particular point of view. Though they are not always humorous, they generally contain an element of irony or at least something incongruous or surprising [9]. The political cartoon constitutes a peculiar genre with its own history, conventions and communicative purposes.

In illustrating the uses and effects of political cartoons, [11] assert that there are three basic paradigms that have appeared in the 20th century which can be identified as the psychoanalytic, the sociological and the rhetorical. The psychoanalytic paradigm stresses that symbolism is "the heartbeat of caricature and that condensation and displacement play central roles in the production and interpretation of political cartoons . . . Cartoons are merely the adult's way of displacing aggression through the adoption of symbolic substitute" (p. 84). On the other hand, the sociological approach goes beyond the mind and motives of comic inventors to emphasize "societal structures which limit and enhance caricature, the symbolic resources available in such a society, and the potential meaning and uses of such symbology within specific sociopolitical contexts" (p. 84). The authors refer to Streicher who says, "caricature is a way of catching at a glance the meaning of an event, a person in the news, or a pictorial summary of a current power constellation" (1965-1966, p. 1). The central function of political cartooning is showing the

interrelationships of people, events and power from a sociological perspective. Third, the rhetorical approach draws upon both the psychoanalytic and sociological perspectives as well as upon Gestalt psychology to concentrate on the interaction of creator, message and audience. The underlying assumption is that graphic art has persuasive dimensions. Cartoons are attempts "not to provide information but confirmation, not to alter attitudes or change minds but to represent an underlying order of things, not to perform functions but to manifest an ongoing and fragile social process" [11], p. 85. Thus the power of political cartoons does not lie at the intent or success of an artist in fostering change but in inviting readers to reaffirming cultural values and beliefs and maintaining them.

#### *2) Characteristics of Political Cartoons*

Political cartoons, a sub-genre of the news discourse genre or *journalese*, is one of the effective multimodal media that employs both verbal and non-verbal elements to construct meaning. Cartooning or caricature first emerged in Italy during the 16th century and was considered a significant part of the newspaper discourse during this era since political cartoons in particular function as tools of communication that update people on current issues. They have a descriptive function since they are characterized by allusion to a socio-political situation, event or person; moreover, factual knowledge is essential for their correct interpretation since they are related to current events [12]. Since political and social issues are mirrored in political cartoons, these are regarded as potential objects of discourse analysis. They not only reflect the thoughts of the public but also have the power to influence them [13]. Cartoons have always been referred to in the literature as "the most neglected genre of political communication" [11], p. 84. It is believed that editorial cartoons provide "a subtle framework within which to view the American political process and its players. Cartoons not only reflect our culture but also invite us to think about its constituent parts and their meaning for our own lives" and that cartooning is a "culture-creating, culture-maintaining, culture-identifying artifact" [11], p. 84.

One key aspect of political cartoons is that they have a satirical nature [12]. They amuse the viewers and impact them due to the spontaneous way a certain message is delivered. They construct social reality through satire, humour, metaphors and symbols, etc. On the one hand, political cartoons may be a mouthpiece of the dominant who is intending to keep status quo for the powerful. Moreover, they show dissatisfaction with injustice and prejudices and they raise voice against social threats; in this way, they reflect public opinion [14]. In fact, [15] illuminates the role of editorial cartoonists as follows:

Editorial cartoonists, in their role as journalists and commentators, participate in the political image-making process. The amusement potential of editorial cartoons, as political satire, sometimes eclipse their discursive function in creating social reality. Cartoons are framed within a unique, condensing form that facilitates representation of candidate images with clear, concise, visually reinforced messages disseminated on a daily basis (p. 2141).

The author further argues that the cartoonist first interprets the image of a candidate and then offers "counter-images developed through a variety of inventional strategies that recreate the world or political discourse". Thus the combination of a factual and fictional world presented by cartoonists expresses "the message-driven process of fantasia". It follows that "the power of the political cartoon is not in its direct, persuasive effects...but in the way it frames and defines what is at issue and participates in the process of fantasia" (p. 2141).

In contrast to comics, the political cartoon is generally contained through a border, the main function of which is to signal a separation between the dramatic cartoon world and the real world of news reporting [16]. However, political cartoons are able to function as narratives since viewers are encouraged to complete in their heads what has been suggested by the depicted moment. A sense of action is usually encouraged through the depiction of movement which is frozen at the moment of representation and the use of vectors: strong, diagonal lines formed obliquely by depicted objects or people which indicate the direction of an action. Some cartoons use conventionalized motion lines leading to or from a moving element [9].

As a matter of fact, [11] argue that the cartoonist turns for a number of resources: political commonplaces, literary/cultural allusions, personal character traits, and transient situational themes. Whereas language may be more precise in expressing some areas of meaning, other meanings can be easily and more effectively represented in images rather than words:

The sequential/temporal characteristic of language-as-speech may lend itself with greater facility to the representation of action and sequences of action; while the spatial display of visual images may lend itself with greater facility to the representation of elements and their relation to each other [17], p. 147.

In the genre of political cartooning, metaphor has been a recurrent device [12]. A metaphor consists of a topic, or 'target', and of a vehicle, a 'source', to which the target is metaphorically compared. An example is "love is a battlefield" where 'love' is the target and 'battlefield' is the source [18], p. 4. From a cognitivist point of view, metaphors can be defined as "sets of mappings between a more concrete or physical source and a more abstract target domain" [19], p. 67. A metaphor is pictorial if both the target and source are cued in the visual mode [18]. In political cartoons the two domains are usually visually integrated (i.e. fusion) since caricatures often overlay the features of a famous personality onto any other being or object [9], pp. 177-178. In political cartoons visual metaphors not only highlight similarities between two different objects but they encourage us to view things in a completely new way and thus re-conceptualize reality. Visual metaphors are frequently more specific than words since they capture shades of meaning that would be difficult to convey through language only [9]. Metaphors are regarded as "rhetorical constructions that condense features and define realities in a particularly potent fashion" [15], p. 2142.

Political cartoons are intended to be suggestive and to

require readers to leap mentally from the level of language to the level of visual meaning. Political cartoons can trigger thought processes about the relationships between seemingly unrelated areas of reality. They often go beyond what pure texts could convey [9].

### 3) *Functions of Political Cartoons*

According to [11], political cartoons serve four functions that include entertainment, aggression reduction, agenda-setting and framing. First, to consider political cartoons as comic is rather simplistic; these can be comic to the degree that they portray the shortcomings of public figures who are suspected of moral or ethical fallacies. Secondly, generally speaking, ordinary people may not take effective action against deceitful or incompetent leaders. However, as forms of communal criticism, cartoons may serve as outlets for protests which might surface in other forms. The ability to vent hostility in socially approved symbolic activities may lessen or even prevent the need for violent aggression. A cartoon might not lead to a subsequent action but it is a symbolic act. Its function is to provide the reader with some sense that the guilty has been punished, thereby providing the reader with internal equilibrium [11].

Thirdly, most political cartoons are invariably mirroring the present reality. It is the reflection of the political presence that makes a political cartoon "an important index to the major issues of the day" [11], p. 92. So long as this mirroring eventually leads to the public discussion of certain issues, the political cartoon may take part in the powerful role of mass media in shaping perceptions of public opinion. In this context, agenda-setting acquires more significance than simply assigning topics in terms of their significance. Rather, it may result in greater public discussion which may result in attitudinal changes among participants in the discussion. Finally, as [11] suggest, the condensed nature of political cartoons whereby a complex issue or event is reduced to a simple metaphorical form provides the reader with a sense of understanding that can serve as a prelude to a subsequent thought or action.

### 4) *Interpretation of Political Cartoons*

Reading a political cartoon involves more than the ability to identify real-life referents of visual representations. What makes political cartoons unique is the way in which they use a fantasy scenario to comment on an aspect of social, political or cultural reality [9]. According to [20], they are "complicated puzzles mixing current events with analogies" (p. 39). Therefore, interpreting cartoons is a complex process whereby readers are required to draw upon a whole range of various 'literacies'. These include wide knowledge of past and current events, a good repertoire of cultural symbols, familiarity with the cartoon genre and conventions in addition to the ability of analytic and critical thinking of real-life events and circumstances [9].

According to [21], political cartoons are basically meant to be read as narrative images. Accordingly, viewers must be able to read not only the visual lexis of a cartoon but also its visual syntax; i.e. the specific patterns for how meanings are put together in images. As [9] opines, social semioticians believe that visual syntax is more flexible than its verbal equivalent since visual structures represent a 'meaning potential' rather than a specific code. A viewer of a political cartoon is always trying to activate the characters depicted

in a cartoon and to work out their story. In addition, understanding the meaning of a cartoon requires the viewer's ability to interpret gestures and facial expressions and to attribute emotions to the depicted characters. In cartoons, facial expression, which is regarded as one of the most important clues to which we react instinctively, is merely suggested by few simple lines which are sometimes more ambiguous than the human face itself. Generally speaking, there is a close relationship between the way viewers read facial expressions and how they interpret the overall narrative meaning of a cartoon [9].

## I. REVIEW OF RELATED LITERATURE

One key trend of research on political cartoons addresses the relationship between political cartoons and reality. Another key trend of research focuses on the mechanisms used for producing the satirical and critical effects of cartoons [13]. With regard to this, exaggeration and distortion are important tools for the cartoonist; other tools are incongruity, condensation and blending [22]. Other studies of political cartoons concentrate on what they can do. Cartoons are capable of communicating "subtle, complex, multilayered messages about people and events in the details of how they are drawn- messages that would be difficult or impossible to express verbally" [23], p. 536. The views expressed may identify with certain ideologies, clarify issues, contrast self with other, and /or reinforce certain positions [24].

However, given the influence and popularity of political cartoons, they have not been given the academic attention that they actually deserve. In relation to the focus of the present study, the review of the literature has yielded a few works in which multimodal analyses of political cartoons are carried out. For example, Sani, Abdullah, Abdullah & Ali [25] explore the role played by political cartoons in setting social agenda in Nigerian newspapers to shape public opinion in recurrent representations highlighting current socio-political issues during a given period of time. Fifty cartoons were taken from two major Nigerian newspapers, Daily Trust and Vanguard, due to their wide readership during 2007-2010. The researchers adopted content analysis in order to identify the themes highlighted in the visual representations. A qualitative method was used to conduct semiotic analysis of the cartoons. The results reveal that Nigerian political cartoons set social agenda by reflecting current issues that people are concerned with. Thus the paper contributes to the research on the cartoon genre by offering insights into this field through agenda setting theory.

Kulikova & Detinko [26] have analyzed the representation of 'others' in British political cartoons. The authors believe that "cartoons as types of multimodal texts are actively exploited in a media determined political discourse for construction of 'other' which is especially characteristic of the British press" (p. 1381). In the inter-cultural perspective, the authors of multimodal texts use generalized visual images where there is an extensive use of well-known metaphors and well-known politicians. On the other hand, in the intra-cultural perspective, there is more focus on the detail and the image reflects the concrete actions of politicians. Facial expressions and posture of the characters create cartoons which are more emotional. The authors state that "in each of the two perspectives, the mechanism of representing the 'other' is different" (p. 1381).

Tehseem & Bokhari [27] have carried out a MDA of political cartoons in Pakistan from two Pakistani newspapers. Twelve political cartoons, six selected from each of the two newspapers, were analyzed in the study. Through their multimodal analysis, the authors show that the newspapers had different attitudes toward the government of Pakistan and the leader of the opposition party in the country. The cartoons reflect the affiliations of the respective media groups which own the two newspapers. Thus political cartoons reflect the pro-government and the anti-government stances depending on the political inclination of the media groups publishing the cartoons.

Shaikh, Tariq & Saqlain [28] have attempted to analyze the political cartoons published during the general election campaign in 2013 in Pakistan. The semiotic analysis of Pakistani political cartoons in this case study reveals how cartoons are used as communicative tools on the internet and print media to highlight current political themes and thus convey significant meanings. That was a critical era when Pakistan experienced political conflicts among various political parties who made use of different resources including print and electronic media in order to persuade voters. Hence, this study investigates the impact of cartoons on people in the absence of political, social and religious milieu.

Samuel [5] has conducted a study that aimed at satirizing the Nigerian climate by identifying the multimodal discourse features of four cartoons selected from January and February, 2016 editions of TELL newsmagazine. These were purposively selected since they highlight political themes and issues. The data were analyzed using the frameworks of MDA, as explained by Kress and van Leeuwen, 2001. The researcher concludes that the political cartoons are meant to enhance easy comprehension of the messages conveyed by them.

## II. RESEARCH METHODOLOGY

### A. Research Design

Since this research explores a political issue as being mirrored in political cartoons, the research design is qualitative in approach. Visual Social Semiotics by Kress & van Leeuwen [1] is adopted as a linguistic framework for analyzing a small set of political cartoons published in Arabic-language newspapers after Trump's Jerusalem move. In analyzing the selected visual compositions, the researcher adopts an interpretative approach which focuses on depth rather than breadth. It is hoped that such an approach would lead to insightful analyses of the cartoons under study.

### B. Selected Sample

The small-size cartoon corpus consists of ten political cartoons selected from a surge of editorial cartoons as highlighted by the ADL, an international Jewish non-governmental organization located in the US, claiming the Israeli domination of the US. The ADLA foregrounded cartoons portrayed in Arabic-language publications in Egypt, Saudi Arabia, UAE, Oman, Iran and UK. They represent anti-semitic cartoons in Arabic-Language media which convey the same message in the wake of the recognition of the US President of Jerusalem as the capital of Israel. They were selected for semiotic analysis in the present study because they portray a particular political issue; hence, the selection of these cartoons is not

subjective. These cartoons can be found at [29].

### C. Theoretical Framework

According to Systemic Functional Linguistics, language is a social semiotic system [30]. Halliday asserts that language is a system network and all the grammatical and other features of language are sets of choices. Furthermore, he claims that all languages involve three meta-functions which are realized simultaneously: ideational function, interpersonal function and textual function [31]. Although this theory was originally developed for the study of language, it has been widely used for analyzing other semiotic resources. Kress & van Leeuwen's *Reading Images* (1990) is always regarded as the pioneering work in interpreting visual compositions. In fact, [1] allow us to read a single image in multiple ways. The authors propose that semiotic tools are artfully represented to realize some particular functions; namely, representational meaning, interactive meaning and compositional meaning [4].

According to [1], representational meaning refers to the way semiotic resources represent objects and relations between them in a particular context. More specifically, it is related to the internal relations between the represented participants, the action(s) they are performing as well as the setting of the circumstance. The two patterns that show the internal relations of visual images are narrative process and conceptual process. The presence of a vector, formed by some part of the represented participant or by an abstraction such as an arrow, is the key signal for distinguishing the two processes.

The narrative process maybe transactional involving an actor (from whom the vector emanates) and a goal (towards which the vector is directed), or they may be non-transactional, involving only an actor. A different kind of narrative processes is the 'Reaction' which is being signified by an eye-line vector. Similarly, it may be transactional, involving both a senser (the one who looks) and a phenomenon (the one looked at), or non-transactional involving a vector only. Additionally, [1] list other three narrative processes: a) Conversion, in which a participant, the 'Relay', is the goal of one action and the actor of another, b) Mental Process, in which a thought bubble serves as a vector between the 'Senser' (from which it emanates) and the Phenomenon, c) Verbal Process, in which a dialogue balloon or any similar device forms a vector between the Sayer (from whom it emanates) and the utterance (participant within the dialogue balloon). The tool that forms the vector or executes the action is regarded as 'Means'. The participant which does not have any vectorial relationship is called the 'Accompaniment'.

Contrary to the dynamic nature of the narrative process, the conceptual process is more stable and it represents participants in terms of types, structure and meaning. In general, conceptual processes can be classified into three sub-processes: classificational process, analytical process and symbolic process. In classificational process, the relationship of taxonomy between the participants is established whereby a set of participants are made 'Subordinate' to another participant 'Super-ordinate'. These relations are established via the ordering of an image. Taxonomy may be either overt where the Super-ordinate and the Subordinates are connected through a tree structure or covert where the Subordinate participants are distributed symmetrically along the axes. The analytical processes

establish a whole-part relationship between two types of participants: Carrier (the whole) and Possessive Attributes (the parts). The Symbolic processes establish the meaning and identity and include the Carrier and the symbolic attribute [1].

Visual communication involves two kinds of participants: represented participants (the people, the places and things depicted in images) and interactive participants (the people who communicate with each other through images, the producers and viewers). It involves three kinds of relations: 1) relations between represented participants; 2) relations between interactive and represented participants; and 3) relations between interactive participants [1], p. 114. According to [1], the communicative function of an image is realized through three types of systems: image act and gaze, social distance and power relations.

The first dimension, the system of image act and gaze, makes a distinction between 'demand' (visual contact with the viewer) and 'offer' (no visual contact). When represented participants look directly at the viewer, vectors, formed by the participants' eye-lines, connect the participants with the viewer. Contact is established even if it is only on an imaginary level. When there is visual contact with the viewer, it is called 'demand' since, following [29], the participant's gaze and gesture, if present, demands that the viewer enter into some kind of imaginary relation with him or her. Other pictures address us indirectly. Here the viewer is the subject of the look. No contact is made. This kind of image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. The second dimension to the interactive meaning of images is related to the choice between close-up, medium shot and long shot, etc. The system of social distance is related to the extent of which the degree of intimacy determined by represented participants appear to the viewer in an image (close-up shot signifies intimacy, long shot signifies impersonal relation, medium shot signifies objects being within the reach of a viewer). Third, the system of involvement and power involves the way participants are positioned along the horizontal and the vertical angles where the horizontal angle shows involvement or detachment (frontal angle involves maximum involvement, oblique angle signifies minimum involvement or maximum detachment). On the other hand, the vertical angle expresses power relations (high angle signifies power, low angle signifies vulnerability and eye level signifies equality). Such power relations may be between the represented participants and the viewer or between the represented participants within an image. These perspective techniques add subjectivity to the images. The removal of subjectivity signifies objectivity and is employed in scientific images. In addition, as [1] suggest, the modality of an image is established by the resemblance of an image to reality as well as the cultural standards with regard to real or unreal of a certain social group.

The relations set up by an image are not exhausted by these patterns only. The third element is the composition of the whole: the way in which representational and interactive elements are made to relate to each other; i.e. the way they are integrated to form a meaningful whole. Pictorial elements can receive stronger or weaker 'stress' than other elements in their vicinity and thus become more or less important 'items of information' in the whole [1], p. 176. Composition relates the representational and interactive

meanings of the image to each other through three interrelated systems: information value, salience and framing [1].

The first aspect of compositional meaning, which is information values, basically means that certain values are given to images based on the placement of elements in a composition. The placement of elements provides them with particular informational values related to the different 'zones' of an image: left as opposed to right, top as opposed to bottom or centre as different from margin. The composition is called 'centred' if it has an element placed at the centre and is called 'polarized' if it does not have any element placed at the centre. The elements can also be assigned information values based on their specific placement on the left and right or at the top and bottom. In a horizontal left-right structure, the left element signifies 'Given'- something the viewer already knows while the right element signifies 'New'- something that requires special attention and is somehow problematic and still needs to be known by the viewer. In using top – bottom structures, the top element signifies the 'Ideal' whereas the bottom element signifies the 'Real'. In contrast to the sense of continuation along the horizontal axis, a sense of contrast or opposition is suggested by the division along the vertical axis. For example, in advertisements, which are designed along the vertical axis, the upper section is made emotionally appealing showing viewers 'what might be' whereas the lower section is made more realistic and informative showing the viewers 'what is'. Moreover, there is usually a sharp line separating the upper section from the lower one. Thirdly, the centre presents "the nucleus of information on which all the other elements are in some sense subservient" [1], p. 206. It plays an important role in establishing a transition between the Given and the New or the Ideal and the Real. The centre of such polarized compositions unites the polarized elements to each other and is called the 'Mediator'. The second aspect of visual composition is salience. In a visual composition, elements are meant to attract the attention of the viewer with varying degrees, as realized by factors such as placement in the foreground or background, relative size, contrasts in colour, difference in sharpness or the way it overlaps with other elements in that composition. Irrespective of where they are placed, salience can create a hierarchy of importance among the elements, selecting some as more worthy of attention than others. Finally, the third aspect of compositional meaning is framing. The absence or presence of framing devices such as dividing lines either connect or disconnect the different elements in an image, thus denoting whether such elements belong or do not belong together in a certain way [1], p. 177. This aspect implies the degree certain elements are visually separated from each other through the use of frame lines, empty space between these elements or other framing devices. Framing renders elements as separate from each other. Framing is usually helpful in defining information value. For instance, there is always a dividing line to make the Ideal-Real structure clear [1].

To answer the research question of the present study, some of these concepts of visual modality are being employed by the researcher in analyzing the political cartoons under investigation.

### III. ANALYSIS AND DISCUSSION

In this section, each of the selected political cartoons is

analyzed by adopting the theory of Visual Social Semiotics, as explained by [1], in order to explore the underlying ideologies. The image shown in each visual composition is first given a brief description, then analyzed in terms of some aspects of the three levels of meaning: representational, interactive and compositional. The analysis of each of the individual visual compositions under investigation is followed an overview of the three aspects of meaning in the selected corpus.

#### A. Analysis of the Selected Corpus

##### 1) Analysis of Political Cartoon 1



**Figure 1. Cartoon 1: Al-Ahram (Egypt), 18 December 2017**

This cartoon (Fig. 1) was published in Al-Ahram newspaper in Egypt on 18th December 2017. In this cartoon the main personality is the Israeli Prime Minister, Benjamin Netanyahu, who is leaning over a number of killed bodies. The other personality depicted in the cartoon is a blindfolded person wearing the American hat and holding a label with the inscription القدس. Both of them join in carrying a wand shaped as Star of David.

With regard to representational meaning, which basically refers to the internal relations between the represented participants, things, the action(s) they are performing as well as the setting portrayed in the image, the cartoonist successfully portrays a narrative process. The Israeli Prime Minister, the main represented participant, is the 'actor' and the ones he is leaning over are the 'goal'. There are two sub-processes here: an action process and a reaction process (transactional reaction). The oblique line across the cartoon draws us to the second main participant in the cartoon, the American personality who is blindfolded. In terms of the conceptual process, the symbolic aspect is the most prominent one: the Israeli Prime Minister symbolizes brutality and ruthlessness while the American personality symbolizes thoughtlessness. Every object in this cartoon is a signifier representing a significant phenomenon. The Israeli Prime Minister represents the Israeli government. The killed bodies signify the Palestinian people who are tortured or killed under the Israeli government. The blindfolded person, wearing the American hat, represents the US which lacks wise vision. The fact that both the US personality and the Israeli Prime Minister are holding a wand shaped as Star of David strongly expresses collaboration and union against Palestinian people. The sign reading القدس signifies Trump's recognition of Jerusalem as the capital of Israel. Another key aspect of the conceptual process is the classificational aspect. An overt taxonomy is realized through depicting the main participant as the super-ordinate whereas both the minor participants (the Palestinians) and the American personality are the subordinates since the former are depicted as much smaller in size and of almost equal

equivalence and the latter is depicted as much smaller in size and in the background. The cartoonist artfully conveys the meaning of the superiority of Israel over the US.

In this cartoon the interactive meaning is mainly realized through two aspects: gaze and power relations. There is no direct contact, either by the main participant or the second participant, with the viewer (offer). The picture addresses us indirectly. Here the viewer is the subject of the look. No contact is made. This kind of image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. The oblique angle used in the cartoon signifies the maximum detachment of the viewer from the world of the represented participants. From the point of view of interactive meaning, the viewer is closer to the main represented participant than to the US personality. Moreover, the image shows a clear contrast between the facial expressions of the American and the Israeli personalities which show satisfaction and the bleeding faces of the Palestinians.

Regarding compositional meaning, first, in this cartoon certain values are given to the visual composition based on the placement of the different elements in the composition. The composition is centred since it has one element placed in the centre. A horizontal left-right structure is being used where the left element, which is the American personality being blindfolded, signifies 'Given'- something the viewer already knows whereas the right element, which is the Israeli Prime Minister leaning over a number of killed bodies, signifies 'New'- something that requires special attention and still needs to be known by the viewer. The right-left axis employed by the cartoonist provides a sense of continuity. Second, salience is the aspect of visual composition that refers to the degree to which any element in such a composition draws the view's attention to it due to factors such as size, colour, placement in the foreground or the way it overlaps with other elements in that composition. In this composition, the main represented participant, the Israeli Prime Minister, is the most salient, the most eye-catching element in the visual representation since it is placed in the foreground and forms the largest element in the picture. Accordingly, special attention is given to the main participant due to its size and its placement in the foreground. The size of the Prime Minister is much larger than that of the victims (salience) highlighting the helplessness of the victims. The huge size of the depicted Prime Minister reflects a sense of power and tyranny. This contrasts with the size of the person representing the US. Jerusalem is now in the hands of the US which collaborates with Israel through holding the same wand. Moreover, the main participant is placed in the foreground while the other participant, the American personality, is placed in the background. Third, framing is another important aspect of compositional meaning in this cartoon. On the one hand, the two represented participants are closely related as they are simultaneously holding the same wand by their hands. On the other hand, there is no space between the main participant and the minor participants he is kneeling on. In this way, the cartoonist successfully delivers the message of the union of the US and Israel on the one hand and the torture of the Palestinians by the Israeli government on the other hand. The cartoonist shows the Israeli Prime Minister as a ruthless character that is ferociously attacking the feeble helpless Palestinians.

In this cartoon, semiotic resources interact to project the

meaning intended by the cartoonist. The communicative message conveyed by the image is the collaboration of Israel and the US in considering Jerusalem as the capital of Israel despite the torture of the Palestinians by Israel.

## 2) Analysis of Political Cartoon 2



**Figure 2. Cartoon 2: Al-Masry Al-Youm (Egypt), 17 December 2017**

Following Trump's recognition of Jerusalem as Israel's capital, this cartoon (Fig. 2), published in Al-Masry Al-Youm newspaper in Egypt on 17th December 2017, is depicting the American President Donald Trump as a circus elephant balancing the globe on its trunk upon the command of its Israeli trainer.

In terms of representational meaning, the cartoonist successfully portrays a narrative process. The main narrative process described in this cartoon is the 'Reaction' which is being signified by an eye-line vector. This process is transactional involving the Israeli trainer as the one who is looking (sensor) at the American President, the one being looked at (phenomenon). There is a clear vector emanating from the eyes of the trainer to the trainee. There are two main participants in the cartoon. The two clear sub-processes are an action and a reaction. The former is clear in the movement of the trainer and the latter in the movement of the American President. In terms of the conceptual process, the most prominent sub-process is the classificational one where the Israeli trainer is the super-ordinate and the American President is the subordinate. Another clear sub-process is the symbolic one. The trainer is a symbol of the authoritarian, domineering role of Israel and the trainee is a symbol of subservience and obedience to the instructions given by the trainer. The ball is a symbol of the whole world that the US is playing with. Though the cartoonist does not use any linguistic tools, the message is successfully conveyed through the use of visual metaphor. Visual metaphor is one key device of projecting meaning in this cartoon: TRUMP IS A CIRCUS ELEPHANT. The target is the American President and the source is a circus elephant. As noted in political cartoons, the two domains are visually integrated (i.e. fusion) where the cartoonist overlays the features of the main represented participant onto another object. Trump is portrayed as an elephant and Israel is portrayed as a trainer. The happy movements of the American President signify utter joy and satisfaction.

In terms of interactive meaning, which is clearly realized in the relationship between the two main participants in the cartoon, the two major aspects are gaze and power systems. There is an oblique line connecting the eyes of the two represented participants. The message intended to be conveyed by the cartoonist is artfully conveyed through power relations: the Jewish trainer is more powerful and

more superior to the US trainee. The oblique angle adopted in the cartoon detaches the viewer from the world of the represented participants.

With regard to compositional meaning, which relates to the way different elements are placed in a visual composition, the horizontal left-right polarization is employed by the cartoonist in representing the two main participants in the cartoon. In this horizontal left-right structure, the left element, being represented by the Israeli trainer, signifies 'Given'- something the viewer already knows while the right element, being represented by the American President, signifies 'New'- something that requires special attention and is somehow problematic and still needs to be known by the viewer. In addition, the huge size of the American President (saliency) compared to the miniature size of the trainer clearly reflects the focus of the visual composition: the playfulness of the US with the whole world. Framing is another important aspect here: the white space between the two participants renders them as separate from each other with each adopting its own position in the allocated setting; a trainer and a trainee in a circus context.

The underlying message conveyed by the portrayal is the domination of Israel over the US. This meaning is projected through a circus context where Israel is the trainer and the US President is the trainee.

### 3) Analysis of Political Cartoon 3



Figure 3. Cartoon 3: Al-Quds Al-Arabi (UK), 8 December 2017

This cartoon (Fig. 3), published in Al-Quds Al-Arabi newspaper in the UK on 8th December 2017, contains two personalities: the Israeli Prime Minister, Benjamin Netanyahu, climbing a ladder while carrying the Old City of Jerusalem and the American President holding a bag labeled "The Arabs' Money".

In terms of representational meaning, the cartoonist portrays a narrative process. The main narrative sub-process is the action one. There are two simultaneous actions: the American president holding the Arab possessions and the Israeli Prime Minister carrying the Old City of Jerusalem with the help of the US. Visual metaphor is deployed in this cartoon to convey certain meanings. One metaphor is: TRUMP IS A THIEF since the American President is portrayed as a thief stealing Arab possessions. In this metaphor, Trump is the target and the thief is the source. Another metaphor is: JERUSALEM IS A GIFT where the target is Jerusalem and the source is a gift. This remarkably expresses the great value of the city to Israel. The strong interplay between the American and the Israeli relationship is represented through the analogy of the back of Trump as a ladder that the Israeli Prime Minister is climbing. The message conveyed is that the US is giving help to Israel to

take over the Palestinian capital while it is attempting to conquer the Arab World. Through the use of visual images, the cartoonist successfully succeeds in conveying the intricate political relationships between the three parties: the US, Israel and the Arab world.

In terms of interactive meaning, one key interpersonal aspect in this cartoon is gaze. The gaze of Trump's eye conveys a sense of cunningness. Furthermore, the facial expressions of the two personalities convey certain meanings: the big smile on Netanyahu's face expresses utter triumph and contentment, and Trump's smile reveals cunningness and malicious intentions. Although the body of the main represented participant is angled away from the plane of the viewer, his gaze is frontal. Here there is a double message: although I am not part of your world, I can still make contact with you from my own different world'.

Regarding compositional meaning, the horizontal left-right polarization structure is being used by the cartoonist where two participants are being shown: on the left hand side is the Jewish leader (Given) and on the right hand side is the American President (New). Saliency is a clear aspect shown in portraying the huge body of the American President which strongly reflects power and sovereignty. Framing is another key aspect of compositional meaning in this cartoon. The closeness in physical distance between the two main personalities as portrayed in the cartoon indicates collaboration and unity.

The underlying message conveyed by the portrayal is the strong union between the US and Israel in seizing Arab possessions and attempting to add Jerusalem to these possessions.

### 4) Analysis of Political Cartoon 4



Figure 4. Cartoon 4: Al-Watan (Oman), 17 December 2017

This cartoon (Fig. 4), published in Al-Watan newspaper in Oman on 17th December 2017, is depicting a Jewish figure giving a thumbs-up while President Trump is declaring Jerusalem as Israel's capital. The cartoon includes two main participants: the American President, Donald Trump, and a Jewish figure. The American President is declaring that "Jerusalem is the capital of Israel". The Jewish figure is giving a thumbs-up as this announcement is being made. The entities of the two personalities are identified via the Star of David on the coat worn by the Jewish figure and the American hat left on the ground in front of the American President.

In terms of representational meaning, the cartoonist successfully portrays a narrative process. The Jewish figure (actor) is pointing (transactional narrative process) with his thumbs-up (means) towards the American President who is holding a microphone (goal) and is uttering the words القدس عاصمة إسرائيل. Here the cartoonist is conveying the meaning

that Israel is content with the declaration of Trump that Jerusalem is the capital of Israel. Another key narrative process in this cartoon is the Verbal Process, in which a dialogue balloon including القدس عاصمة اسرائيل forms a vector between the Sayer (from whom it emanates) and the utterance (participant within the dialogue balloon). The tool that forms the vector or executes the action is regarded as Means. One of the key elements in this cartoon is the headphones which connect the two personalities together. This symbolizes the collaboration between the two entities. The gesture made by the Jewish figure indicates satisfaction with the announcement. At the macro level, it indicates the support given to the US by Israel.

The oblique angle adopted by the cartoonist in the cartoon signifies the maximum detachment of the viewer from the world of the represented participants.

With regard to compositional meaning, which relates to the way different elements are placed in the composition, the horizontal left- right polarization structure is being used by the cartoonist where two participants are being shown: on the left hand side is the Jewish leader (Given) and on the right hand side is the American President (New). The bodies of the two represented participants lean forward and thus form oblique lines which create two similar vectors. The two action parallel processes suggest the equal importance of the two characters in the cartoon by presenting two represented participants in almost the same way. The images of the two characters are given identical salience in the cartoon. They are placed at the left side and the right side separately leaving the center of the picture to be a margin. Moreover, they are taking the same posture and are dressed in almost the same colour. Framing is another key aspect in this composition: the white space between the two participants renders them separate from each other; however, they are connected via the headphones. This serves as a framing device that connects the elements in the pictorial composition.

The underlying message conveyed by the cartoonist in this image is the contentment and satisfaction of Israel on announcing Jerusalem as Israel's capital by the US President.

##### 5) Analysis of Political Cartoon 5



**Figure 5. Cartoon 5: Al-Youm Al-sabea (Egypt), 8 December 2017**

In contrast to previous cartoons, this cartoon (Fig. 5), published in Al-Youm Al-sabea newspaper in Egypt on 8th December 2017, contains only one personality: the American President, Donald Trump. He is portrayed sitting at a table and holding a fork in each of his hands. The plate in front of him contains a killed pigeon. On his left, there is a temple. The cartoonist successfully portrays a narrative process which is non-transactional involving a vector only.

In terms of the conceptual process, which is less dynamic than the narrative process and renders participants in a visual composition in terms of types or structures, every object in this cartoon is a signifier that represents a particular phenomenon. The cap that the US President is wearing represents the Jewish identity and so is the temple on his left side. The killed pigeon symbolizes peace which has ended up. The plant which symbolizes peace is portrayed as feeble and fragile. Overall, the act of eating portrayed in the cartoon symbolizes devouring.

The interactive function of this image is realized through the gaze where there is visual contact with the viewer (demand). The represented participant is looking directly at the viewer's eyes. Here the vector, formed by participants' eye-lines, connects the participant with the viewer; contact is established. Following Halliday (1985), the participant's gaze and the gesture, if present, demands that the viewer enter into an imaginary relation with the represented participant. The figure is a close shot where only the face and the shoulders of the represented participant is shown. The close shot serves to focus on the facial expressions and suggests engagement with the viewer. The close shot aims to capture subtle facial expressions combined with their body language or surrounding environment that is necessary to provide context. The main represented participant faces the viewer frontally. The facial expressions of the main participants reflect inner feelings of cruelty and ruthlessness.

With regard to compositional meaning, this visual composition is 'centred' since it has only one element placed at the centre.

The communicative message conveyed by this visual composition is the domination of Israel over the US with regard to considering Jerusalem as Israel's capital which would result in violating any attempts of maintaining peace and, hence, evoking violence.

##### 6) Analysis of Political Cartoon 6



**Figure 6. Cartoon 6: Al-Quds Al-Arabi (UK), 6 December 2017**

This cartoon (Fig. 6), published in Al-Quds Al-Arabi newspaper in UK on 6th December 2017, contains two personalities: the US president, Donald Trump and the Jewish Prime Minister, Benjamin Netanyahu. The podium having the inscription خطاب ترامب indicates the setting where the American President is giving his political speech on declaring Jerusalem as the capital of Israel.

The narrative process in this cartoon involves an 'actor' (from whom the vector emanates) and a 'goal' (towards which the vector is directed). The Jewish Prime Minister is the 'actor' and the US President is the 'goal'. Visual metaphor is one key device of projecting meaning in this cartoon: TRUMP IS A PUPPET. The target is the American President and the source is a puppet. The two domains are visually integrated (i.e. fusion) where the cartoonist overlays the features of the main represented participant onto another

object. Portraying the American President as a small puppet which is controlled and moved by the Jewish Prime Minister symbolizes the political influence of Israel over the US. The cartoonist draws a number of stars at the background which indicates the domineering role of Israel in the depicted situation. Through the deployment of visual images, the cartoonist successfully conveys a clear message: Israel is controlling the political decision and action made by the US.

The communicative function of the image is realized through the system of gaze and power relations which is between the two represented participants in the image. The picture addresses us indirectly. Here the viewer is the subject of the look. No contact is made with either of the two represented participants. This image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. Superiority is assigned to the Jewish personality who is in control of the US President. The oblique angle used in the cartoon signifies the minimum involvement of the viewer with the world of the represented participants.

With regard to compositional meaning, there is a clear contrast in the size of two personalities symbolizing Israel and the US. The miniature size of the American President and its movement, which is controlled by the Israeli Prime Minister, reflects the power and the great domineering role of Israel on the US. Framing is another key aspect in this visual composition. It renders the two main personalities in this cartoon close to each other as there is no white space between them. This strongly conveys a sense of closeness in relationship.

The underlying message conveyed by the cartoonist in this image is the domination of Israel over the US with regard to announcing Jerusalem as Israel's capital.

7) Analysis of Political Cartoon 7



Figure 7. Cartoon 7: Al-Ryadh (Saudi Arabia), 10 December 2017

This cartoon (Fig. 7), published in Al-Ryadh newspaper in Saudi Arabia on 10th December 2017, has two personalities: the American President, Donald Trump and a Jewish figure. The former is wearing glasses and holding binoculars, each being shaped as the Star of David and the latter is carrying a sign reading القدس عاصمة اسرائيل. The cartoon has the caption الانحياز الاسرائيلي.

In terms of the narrative process, the main narrative sub-process is the action one. The main action represented in the cartoon is the American president attempting to visualize the world with Jewish eyes. The main theme of the cartoon which is the American bias towards Israel is successfully and artfully expressed through visual images. The image of the Star of David on the glasses and the binoculars powerfully conveys the message sent by the cartoonist.

The interactive meaning in this cartoon is mainly realized through the system of gaze and social distance. The picture

addresses us indirectly. Here the viewer is the subject of the look. No contact is made with either of the two represented participants. This image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. Regarding social distance, which is related to the extent to which the degree of intimacy determined by the represented participants appears to the viewer, the degree of intimacy between the two represented participants is clearly shown. The oblique angle used in the cartoon signifies the detachment of the viewer from the world of the represented participants. The close shot serves to capture subtle facial expressions and surrounding environment.

Saliency is a clear aspect of the compositional meaning in this cartoon. The viewer's attention is obviously drawn towards the element in the foreground of the visual composition. The American President is at the centre of the composition (saliency/ new). Behind him in the background is a Jewish figure carrying a sign reading القدس عاصمة اسرائيل (given). This is also realized through the difference in size between the two participants. Framing is another key aspect of the compositional meaning. With no white space between the two represented participants in the cartoon, it renders them close to each other.

In this image the various semiotic resources, both verbal and non-verbal, interact in projecting the underlying meaning: the bias of the US towards Israel with regard to the announcement of Jerusalem as Israel's capital.

8) Analysis of Political Cartoon 8



Figure 8. Cartoon 8: Al-Madina (Saudi Arabia), 8 December 2017

This cartoon (Fig. 8), published in Al-Madina newspaper in Saudi Arabia on 8th December 2017, contains two personalities: the American President, Donald Trump, and a Jewish personality. The former is portrayed as presenting Jerusalem as a gift to the Jewish personality.

The cartoonist successfully portrays a narrative process. The two main sub-processes are an action and a reaction. The American President (actor) is sending a gift (goal) to the Jewish people. The reaction of the Jewish person lies in his readiness to receive the gift with contentment and satisfaction. Visual metaphor is a key device for projecting meaning in this cartoon: JERUSALEM IS A CAKE. The target is the Palestinian city and the source is a cake. The two domains are physically merged into a unified object. This strongly expresses the great value of the city to Israel.

The communicative function in this image is realized through the system of gaze and social distance. The picture addresses us indirectly. Here the viewer is the subject of the look. No contact is made with either of the two represented participants. This kind of image is called an 'offer'- it offers the represented participants to the viewer as items of

information or as objects of contemplation. As far as social distance is concerned, the degree of intimacy between the two represented participants is clear. The oblique angle used in the cartoon signifies the detachment of the viewer from the world of the represented participants. The close shot serves to capture subtle facial expressions: the decisiveness of the US President and the contentment of the Jewish Personality.

With regard to compositional meaning, a horizontal left-right polarization structure is being used by the cartoonist. Thus it shows two participants: the Jewish figure shown at the left hand side of the image (given) while the American President is shown at the right hand side (new). The cartoonist establishes Trump as much higher in stature than the Israeli figure (salience) as indicated by the difference in their sizes. The underlying meaning is that Trump is presenting Jerusalem as a gift to Israel. Framing is another key aspect of this visual composition. The way the two participants are framed with little white space between them renders the meaning of closeness and intimacy.

The communicative message delivered by the cartoonist in this portrayal is the collaboration between Israel and the US. Jerusalem is presented as a gift sent to Israel by the US President.

#### 9) Analysis of Political Cartoon 9



**Figure 9. Cartoon 9: Al-Ittihad (UAE), 17 December 2017**

Following President Trump's recognition of Jerusalem as Israel's capital, this cartoon (Fig. 9), published in Al-Ittihad newspaper in the UAE on 17th December 2017, is portraying Uncle Sam while throwing off his hat to reveal a Jewish skullcap with a Star of David. The cartoon contains only one personality and has the caption *العم سام*.

The narrative process portrayed in this cartoon is non-transactional since it involves only an actor without a goal. There is a vector emanating from the represented personality and moving us to his hat. In terms of the conceptual process, each element in the cartoon is a signifier. Uncle Sam represents the US and the skullcap is a symbol of the Jewish identity.

In terms of interactive meaning in this cartoon, there is no visual contact with the viewer (offer). The picture addresses us indirectly. Here the viewer is the subject of the look. No contact is made with the main represented personality. This kind of image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. The oblique angle used in the cartoon signifies the maximum detachment of the viewer from the world of the represented participant.

With regard to compositional meaning, this visual

composition is 'centred' since it has one element placed at the centre. In this cartoon, conventionalized motion lines are being used by the cartoonist leading from the moving element.

The main message conveyed by the cartoonist in this image is the identification of the US with Israel.

#### 10) Analysis of Political Cartoon 10



**Figure 10. Cartoon 10: Fars newspaper (Iran), 16 December 2017**

This cartoon (Fig. 10), published in Fars newspaper in Iran on 16th December 2017, is depicting the American President, Donald Trump, driving off a cliff in a car which is marked with the Star of David.

The narrative process depicted in the cartoon is non-transactional involving only one actor (the US President) with no goal. The intended meaning, which is the Israeli domination of the US, is ostensibly conveyed through the Star of David on the car driven by Trump.

With regard to interactive meaning, there is no visual contact with the viewer (offer). The picture addresses us indirectly. Here the viewer is the subject of the look. No contact is made with the main represented participant. This image is called an 'offer'- it offers the represented participants to the viewer as items of information or as objects of contemplation. Moreover, the communicative function of the image is basically conveyed through the system of involvement and power: the low angle signifies power. Low angle gives the impression of triumph and superiority. If the represented participant is seen from a low angle, then the relation between the represented participant and the interactive participant is depicted as one in which the represented participant has power over the interactive participant. Such power relations is between the represented participant and the viewer [1]. In this cartoon the angle is low. The US President is towering high as if he is looking down at the viewer. He is depicted as if he exercising symbolic power over us.

In visual compositions elements can be assigned information values based on their specific placement on the left and right or at the top and bottom. In this cartoon a top-bottom structure is being used by the cartoonist where the top element signifies the 'Ideal' and the bottom element signifies the 'Real'. The opposition between top and bottom is strongly emphasized: the constituent elements placed on the top are presented as the Ideal- the aspirations of the President whereas what is placed at the bottom is presented as the Real. In this cartoon, conventionalized motion lines are being used by the cartoonist leading to the moving element.

The communicative message conveyed by the cartoonist in this portrayal is the identification of the US with Israel

and the high ambitions of the US in realizing Jerusalem as Israel's capital.

### B. Aspects of Meaning in the Selected Corpus

#### 1) Representational meaning

First, with regard to the narrative processes depicted in the political cartoons under study, there are variations among the selected visual compositions. In some cartoons, the narrative process is transactional involving an actor (from whom the vector emanates) and a goal (towards which the vector is directed); e.g. Fig. 1 and Fig. 4. In other cartoons, the narrative process is non-transactional, involving only an actor; e.g. Fig. 5, Fig. 9 and Fig. 10. A different kind of narrative processes is the "Reaction" which is being signified by an eye-line vector. Sometimes it is transactional, involving both a senser (the one who looks) and a phenomenon (the one looked at); e.g. Fig. 2, or non-transactional involving a vector only; e.g. Fig. 5. Second, with regard to the conceptual process, the symbolic aspect is the most prominent one. A clear example is in Fig. 1 where the Israeli Prime Minister symbolizes brutality and ruthlessness and the American personality symbolizes thoughtlessness. Next is the classificational aspect where the Jewish personality is often rendered as the super-ordinate and the American personality is the subordinate; e.g. Fig. 1, Fig. 2 and Fig. 6. Finally, visual metaphor is a recurrent device in the selected cartoons which plays a key role in realizing certain meanings. Clear examples are in Fig. 2 where the US President is portrayed as a circus elephant playing with a ball which signifies the whole world and Fig. 3 where the US President is portrayed as a thief stealing Arabs' money.

#### 2) Interactive meaning

The communicative function of images, which mainly relates in the selected cartoons to the relationship between the represented participants in the each of the cartoons and the viewer, is mainly conveyed through gaze and power relations. With regard to the system of image act and gaze, a distinction is made between 'demand' where there is visual contact with the viewer; e.g. Fig. 5 and 'offer' where there is no visual contact; e.g. Fig. 1, Fig. 2, Fig. 7, Fig. 8, Fig. 9 and Fig. 10. In most of the selected cartoons; e.g. in Fig. 7, Fig. 8 and Fig. 9, the oblique angle is adopted by the cartoonist to signify the detachment of the viewer from the world of the represented participants. Frontal angle as in Fig. 5 signifies maximum involvement with the viewer of the image. The close shot, as in Fig. 5, Fig. 7 and Fig. 8, serves to capture the subtle facial expressions of the US President.

#### 3) Compositional meaning

In most of the cartoons under study, the cartoonists adhere to a basic left-right structure which signifies a sense of continuity. In some of the selected cartoons; e.g. Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 8, the left-right polarization is being used where the left element signifies 'Given'- something the viewer already knows while the right element signifies 'New'- something that requires special attention and is somehow problematic and still needs to be known by the viewer. In one cartoon (Fig. 10), the top-bottom structure is being used where the top signifies the 'Ideal' and the bottom signifies the 'Real'. A second prominent aspect of compositional meaning that contributes to realizing meaning is salience which refers to the degree to which any element in such a composition draws the view's attention to it due to factors such as size, colour, placement in the foreground;

e.g. the huge size of Netanyahu in Fig. 1 or the way it overlaps with other elements in that composition. A third prominent aspect of compositional meaning is framing which implies the degree certain elements are visually separated from each other through the use of frame lines; e.g. the way the Israeli personality and the US President overlap in Fig. 3, or empty space between the elements; e.g. in Fig. 2 where there is some space between the Israeli personality as a trainer and the US President as a trainee in a circus context. Framing renders elements as either close or separate from each other.

### IV. CONCLUDING REMARKS

This paper was an attempt to explore a previously under-researched aspect of political cartoons- analyzing political cartoons from a multimodal perspective. The aim of this research was to analyze selected political cartoons on Trump's recognition of Jerusalem as Israel's capital using the framework of Visual Social Semiotics, as explained by [1], as a methodological framework. In light of analyzing the selected cartoons published in Arabic-language media in the wake of this event, it is proved that semiotic resources used by the cartoonists function in realizing the intended meaning of the cartoons: Israeli and Jewish domination of the US. Understanding the different aspects of meaning- representational, interactive and compositional- is a prerequisite for understanding the intended meaning inherent in each of the visual compositions.

It can be claimed that this research has its significance in both theory and practice. First, this research has demonstrated that the political cartoon constitutes an effective multimodal genre that comprises both linguistic and non-linguistic devices that convey meaningful messages and, accordingly, help in setting social agenda and initiating social reform. Political cartoons constitute one of the effective media that not only disseminate information but depict social events and realities as well as render social representations of political figures. Second, it contributes to the research on the political cartoon genre by opening a new dimension through analyzing the semiotic resources employed in political cartoons rather than restricting the analysis to linguistic elements only. Third, it testifies the applicability of the Visual Semiotics framework in analyzing political cartoons. The application of a MDA framework to the investigation of the selected cartoons has proved that visual compositions are communicative tools that are embedded with meaning and that these contribute to conveying the implicated messages. This is consistent with the results of previous related studies which identify the significance of the role of political cartoons in addressing and highlighting social and political themes and issues. Finally, this research provides a more comprehensive perspective of the analysis of political cartoons which will enhance viewers' appreciation and understanding of the different modalities used in political cartoons.

It can be concluded that the integration of different modalities in political cartoons deserves further exploration; hence, this research might serve as a springboard for conducting further research on the analysis of other political cartoons from a multimodal perspective due to the rich communicative characteristics inherent in them.

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# The Effects of Self-Reflections on Intercultural Communication Competency: A Case Study of the University of Arkansas-Fort Smith

JaeYoon Park

**Abstract**—The ability to communicate effectively across different cultures is a necessary skill in today’s increasingly globalized world. Intercultural communication competency (ICC) is a way of being that benefits all members of a society in their living, learning, and working environments as well as in the context of mediated communications. This study examines the effects of self-reflection processes on the improvement of intercultural communication skills focusing on college students at the University of Arkansas-Fort Smith. A total of sixty-nine students’ works were analyzed based on the data collected in the past three years (2016, 2017 and 2018). The students in the “Culture and Communication” class, each spring, completed the Diversity Awareness Profile (DAP) survey as a pre- and post-test for the course. DAP is a self-assessment tool designed by Karen Stinson and widely used in college classes, companies, and organizations to evaluate an individual’s behaviors in various intercultural settings. It can assist individuals in becoming more aware of diversity issues and also provide a foundation for developing strategies for modifying any undesirable behavior they may discover in the assessment. In addition to the DAP surveys, the students also submitted self-reflection essays that discussed their own scores.

The University of Arkansas-Fort Smith is a small regional university located in the Bible Belt of the United States. White, Christian, working-class students dominate its student population. The students, whose data were collected, were predominantly seniors in college majoring in either Media Communication or International Business. Approximately, 80% of the students increased their scores, and 42% of them moved forward to a new category. The findings also indicate that the students in the underrepresented groups (i.e., women, minority, and international students) show less change in their scores and behaviors than the rest of the students (i.e., white heterosexual male students). These findings, in most part, result from the fact that the underrepresented students were already aware of diversity and intercultural issues through their personal experiences before taking the class. The white heterosexual male students demonstrated the greatest improvements, judging from their DAP scores (pre- and post-tests) and self-reflection essays. Through the class assignments and discussions, which emphasized critical thinking and self-reflections, the latter group of students not only became more aware of the meaning of their own words and behaviors, but they were also able to develop greater proficiency in intercultural communication. This e-poster presentation will analyze the findings of this research data, and also discuss the pedagogical implications of such results.

**Keywords**—Cross cultural communication, diversity awareness survey, self-reflections, underrepresented students.

# Conceptualizing Conflict in the Gray Zone: A Comparative Analysis of Diplomatic, Military and Political Lenses

John Hardy, Paul Lushenko

**Abstract**—The twenty-first century international security order has been fraught with challenges to the credibility and stability of the post-Cold War status quo. Although the American-led international system has rarely been threatened directly by dissatisfied states, an underlying challenge to the international security order has emerged in the form of a slow-burning abnegation of small but significant aspects of the status quo. Meanwhile, those security challenges which have threatened to destabilize order in the international system have not clearly belonged to the traditional notions of diplomacy and armed conflict. Instead the main antagonists have been both states and non-state actors, the issues have crossed national and international boundaries, and contestation has occurred in a “gray zone” between peace and war.

Gray zone conflicts are not easily categorized as military operations, national security policies or political strategies, because they often include elements of diplomacy, military operations, and statecraft in complex combinations. This study applies three approaches to conceptualizing the gray zone in which many contemporary conflicts take place. The first approach frames gray zone conflicts as a form of coercive diplomacy, in which armed force is used to add credibility and commitment to political threats. The second approach frames gray zone conflicts as a form of discrete military operation, in which armed force is used sparingly and is limited to a specific issue. The third approach frames gray zones conflicts as a form of proxy war, in which armed force is used by or through third parties, rather than directly between belligerents.

The study finds that each approach to conceptualizing the gray zone accounts for only a narrow range of issues which fall within the gap between traditional notions of peace and war. However, in combination, all three approaches are useful in explicating the gray zone and understanding the character of contemporary security challenges which defy simple categorization. These findings suggest that coercive diplomacy, discrete military operations, and proxy warfare provide three overlapping lenses for conceptualizing the gray zone and for understanding the gray zone conflicts which threaten international security in the early twenty-first century.

**Keywords**—Gray zone, international security, military operations, national security, strategy.

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# Applications of Multi-Path Futures Analyses for Homeland Security Assessments

John Hardy

**Abstract**—A range of future-oriented intelligence techniques are commonly used by states to assess their national security and develop strategies to detect and manage threats, to develop and sustain capabilities, and to recover from attacks and disasters. Although homeland security organizations use futures intelligence tools to generate scenarios and simulations which inform their planning, there have been relatively few studies of the methods available or their applications for homeland security purposes.

This study presents an assessment of one category of strategic intelligence techniques, termed Multi-Path Futures Analyses (MPFA), and how it can be applied to three distinct tasks for the purpose of analyzing homeland security issues. Within this study, MPFA are categorized as a suite of analytic techniques which can include effects-based operations principles, general morphological analysis, multi-path mapping, and multi-criteria decision analysis techniques. These techniques generate multiple pathways to potential futures and thereby generate insight into the relative influence of individual drivers of change, the desirability of particular combinations of pathways, and the kinds of capabilities which may be required to influence or mitigate certain outcomes.

The study assessed eighteen uses of MPFA for homeland security purposes and found that there are five key applications of MPFA which add significant value to analysis. The first application is generating measures of success and associated progress indicators for strategic planning. The second application is identifying homeland security vulnerabilities and relationships between individual drivers of vulnerability which may amplify or dampen their effects. The third application is selecting appropriate resources and methods of action to influence individual drivers. The fourth application is prioritizing and optimizing path selection preferences and decisions. The fifth application is informing capability development and procurement decisions to build and sustain homeland security organizations.

Each of these applications provides a unique perspective of a homeland security issue by comparing a range of potential future outcomes at a set number of intervals and by contrasting the relative resource requirements, opportunity costs, and effectiveness measures of alternative courses of action. These findings indicate that MPFA enhances analysts' ability to generate tangible measures of success, identify vulnerabilities, select effective courses of action, prioritize future pathway preferences, and contribute to ongoing capability development in homeland security assessments.

**Keywords**—Homeland security, intelligence, national security, operational design, strategic intelligence, strategic planning.

# Circadian Expression of MicroRNAs in Colon and Its Changes during Colorectal Tumorigenesis

Kateřina Balounová, Jiří Pácha, Peter Ergang, Martin Vodička, Pavlína Kvapilová

**Abstract**—MicroRNAs are small non-coding RNAs involved in a wide range of physiological processes. Post-transcriptional regulation of gene expression by microRNAs gives the organism a further level of control of the gene-expression program and the disruption of this microRNA regulatory mechanism seems to increase the risk of various pathophysiological conditions including tumorigenesis. To the present day, microRNAs were shown to participate in the mayor signalization pathways leading to tumorigenesis, including proliferation, cell cycle, apoptosis and metastasis formation. In addition, microRNAs have been found to play important roles in the generation and maintenance of circadian clock. These clocks generate circadian rhythms, which participate in a number of regulatory pathways. Disruption of the circadian signals seems to be associated with the development and the progression of tumours including colorectal cancer. We investigated therefore whether the diurnal profiles of miRNAs linked to tumorigenesis and regulation of circadian clock are changed during tumorigenesis. Based on published data we chose 10 microRNAs linked to tumorigenesis or circadian clock (let-7b-5p, miR-1-3p, miR-106b-5p, miR-141-3p, miR-191-5p, miR-20a-5p, miR-25-3p, miR-29a-3p, miR-34a-5p and miR-93-5p) and compared their 24-hr expression profiles in healthy and in chemically induces primary colorectal tumours of 52week-old mice. Using RT-qPCR we proved circadian rhythmicity in let-7b-5p, miR-106b-5p, miR-141-3p, miR-191-5p, miR-20a-5p, miR-25-3p, miR-29a-3p and miR-93-5p in healthy colon but not in tumours. The acrophases of miR-106b-5p, miR-141-3p, miR-191-5p, miR-20a-5p, miR-25-3p and miR-93-5p were reached around CT 24, the acrophases of let-7b-5p and miR-29a-3p were slightly shifted and reached around CT 21. In summary, our results show that circadian regulation of some colonic microRNAs are greatly affected by neoplastic transformation.

**Keywords**—Circadian rhythm, colon, colorectal cancer, microRNA, tumorigenesis.

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# An Observational Study Assessing the Baseline Communication Behaviors among Healthcare Professionals in an Inpatient Setting in Singapore

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**Keywords**—Healthcare Communication, Healthcare Management, Nursing, and Qualitative Observational Study.

**Abstract**—Background: Synchronous communication, such as telephone calling, remains the standard communication method between nurses and other healthcare professionals in Singapore public hospitals despite advances in asynchronous technological platforms, such as instant messaging. Although miscommunication is one of the most common causes for lapses in patient care, there is a scarcity of research characterizing baseline inter-professional healthcare communications in a hospital setting due to logistic difficulties. Objective: This study aims to characterize the frequency and patterns of communication behaviours among healthcare professionals. Methods: The one week observational study was conducted on Monday through Sunday at the nursing station of a cardiovascular medicine and cardiothoracic surgery inpatient ward at the National Heart Centre Singapore. Subjects were shadowed by two physicians for sixteen hours or consecutive morning and afternoon nursing shifts. Communications were logged and characterized by type, duration, caller, and recipient. Results: A total of 1,023 communication events involving the attempted use of the common telephones at the nursing station were logged over a period of one week, corresponding to a frequency of one event every 5.45 minutes (SD 6.98, range 0-56 minutes). Nurses initiated the highest proportion of outbound calls (38.7%) via the nursing station common phone. A total of 179 face-to-face communications (17.5%), 362 inbound calls (35.39%), 481 outbound calls (47.02%), and 1 emergency alert (0.10%) were captured. Average response time for task-oriented communications was 159 minutes (SD 387.6, range 86-231). Approximately 1 in 3 communications captured aimed to clarify patient-related information. The total duration of time spent on synchronous communication events over one week, calculated from total inbound and outbound calls, was estimated to be a total of 7 hours. Conclusion: The results of our study showed that there is a significant amount of time spent on inter-professional healthcare communications via synchronous channels. Integration of patient-related information and use of asynchronous communication channels may help to reduce the redundancy of communications and clarifications. Future studies should explore the use of asynchronous mobile platforms to address the inefficiencies observed in healthcare communications.

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# Detailed Sensitive Detection of Impurities in Waste Engine Oils Using Laser Induced Breakdown Spectroscopy, Rotating Disk Electrode Optical Emission Spectroscopy and Surface Plasmon Resonance

Cherry Dhiman, Ayushi Paliwal, Mohd. Shahid Khan, M. N. Reddy, Vinay Gupta, Monika Tomar

## I. INTRODUCTION

**Abstract**—The laser based high resolution spectroscopic experimental techniques such as Laser Induced Breakdown Spectroscopy (LIBS), Rotating Disk Electrode Optical Emission spectroscopy (RDE-OES) and Surface Plasmon Resonance (SPR) have been used for the study of composition and degradation analysis of used engine oils. Engine oils are combustible fuel, the soot of which contains the hazardous components in the form of fine, coarse and ultrafine particles consisting of particulates matter (PM) and wear metal elements. Such coarse PM and toxic elements are extremely dangerous for human health that can cause respiratory and genetic disorder in humans. The combustible soot from thermal power plants, industry, aircrafts, ships and vehicles can lead to the environmental and climate destabilization which is not good for various species living on the planet, land, water and agriculture which contributes towards global warming. The detection of such toxicants in the form of elemental analysis is a very serious issue for the waste material management of various organic, inorganic hydrocarbons and radioactive waste elements. In view of such important points, the current study on used engine oils was performed. The fundamental characterization of engine oils was conducted by measuring water content and kinematic viscosity test that proves the crude analysis of the degradation of used engine oils samples. The microscopic quantitative and qualitative analysis was presented by RDE-OES technique which confirms the presence of elemental impurities of Pb, Al, Cu, Si, Fe, Cr, Na and Ba lines in for used waste engine oil samples in few ppm. The presence of such impurities elemental lines were confirmed by LIBS spectral analysis at various transition levels of atomic line. The recorded transition line of Pb confirms the maximum degradation which was found in used engine oil sample no. 3 and 4. Apart from the basic tests, the calculations for dielectric constants and refractive index of the engine oils were performed via SPR analysis.

**Keywords**—Laser induced breakdown spectroscopy, rotating disk electrode optical emission spectroscopy, surface plasmon resonance, ICCD spectrometer, Nd:YAG laser, engine oil.

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**T**HE sensitive detection of composition of waste engine oil as a renewable fuel is a subject of great concern due to issues related to environmental security and human health. Every year almost 24 million metric tons of waste engine oil is disposed all around the world [1]. Before disposal, the detection of elemental contamination is a potential tool to avoid the risks related to clean air environment protocol. The continuous monitoring stages of lubricants at many intervals are extremely essential in order to keep check on the physical, chemical, mechanical, and optical properties which provide the information about the operation of machinery parts at different levels of their utility and functioning. Waste engine oils consist of aliphatic and aromatic hydrocarbons which is a source of fuel energy. The most basic technique of pyrolysis has proven to be one of the best ways to clean the waste engine oil and made it as a source of fuel after recycling. The other fundamental techniques for the detection of impurities in engine oils are total acid number (TAN), total base number (TBN), blotter test and water content measurement [2].

Recent developments in the laser based experimental studies by various research groups and the experimental methods such as RDE-OES, SPR and LIBS have contributed tremendously for the critical studies for the detection of toxicants in few concentrations ranging from ppm to ppt traces [3]-[5]. Harith et al. presented the percentage decay of engine oils using LIBS technique by measuring the CN and C2 molecular stages collected from various cars with different mileage [6]. The studies by Mohammed et al. show the elemental analysis on crude oil by spectrum studies [6]. The reported results by Sagi et al using induced coupled plasma spectroscopy based (ICP-MS) have illustrated the comparison on engine oils with the elemental analysis based technique such as energy dispersive X-ray fluorescence spectroscopy (ED-XRFS) [7]-[9]. The unique features of RDE-OES and LIBS techniques comprise the detection of multi-elemental traces in concentration of few parts per million levels. For last several decades, LIBS has proven to be one of the best spectroscopic techniques for the standoff analysis of the samples for their elemental composition in trace concentrations levels. In LIBS, high power pulsed laser was used to excite the sample on which plasma was generated. From LIBS plasma, the information about the spectral features of atomic transition lines can be studied

and investigated. However, due to complexity in handling the LIBS spectral data, RDE-OES technique is more adaptable. Also, the comparatively faster detection accuracy in sub ppm levels using this technique makes it more reliable than other established methods for the degradation of waste engine oils. Contamination of engine oils contains the impurity elements due to wear and tear which changes its optical parameters such as refractive index and extinction coefficient. In such a direction, SPR technique is another more accurate and sensitive optical method in comparison to the various other detection methods such as Fourier transform infrared spectroscopy and electrochemical methods [10-12]. SPR technique relies on the excitation of surface plasmon wave at the metal-dielectric interface by the evanescent wave using various coupling arrangements. The resonance condition can be achieved when the propagation constant of SPW matches the propagation constant of the evanescent wave which is termed as surface Plasmon resonance. SPR can be studied in angular interrogation and wavelength interrogation mode. In angular interrogation method, SPR plots consist of variation of the reflectance (i.e. normalised reflected intensity) versus incident angle which is further used to determine the dielectric constant (or refractive index) [13].

In the present research work, the contamination analysis was validated by other optical techniques such as RDE-OES, LIBS and the comparison of dielectric constants of different engine oil samples have been studied using SPR technique.

## EXPERIMENTAL

### A. WATER CONTENT MEASUREMENT

Presence of water content in the engine oils is one of the major problems that can result the damage of the machinery operations by forming small sized fragments of by-products and accelerate the process of oxidation. Due to this reason, the heavy machinery based engines for their longer working hours of operations require the monitoring for water check such as machinery in industrial sector, aircraft and diesel engine in railways. Hence, engine oil samples were collected to examine their water content status. The hot plate was used to check the water content and the presence of no crackling sound ensures the presence of no water content in any percentage in all four samples.

**TABLE I**

WATER CONTENT MEASUREMENTS IN ENGINE OIL BY CRACKLING SOUND ON HOT PLATE

S. No.	SAMPLE	Water Content
1.	Oil No.1	No
2.	Oil No. 2	No
3.	Oil No. 3	No
4.	Oil No. 4	No

### B. KINEMATIC VISCOMETRIC STUDIES

Another important method is kinematic viscometric which has been adopted by the engine oil monitoring laboratories as a routine work. In the viscometer studies, viscosity measurements were performed using kinematic viscometric bath. In this technique, engine oil was filled in a capillary tube upto the mark of the viscosity action of

capillary tube and then it was kept in the viscometer bath and the time was measured so that the engine oil would perform the capillary action. 'T' time was taken by the capillary action multiplied by the tube constant gives the viscosity of the engine oil. The temperature of viscometer bath chamber was maintained at 40°C and tube was placed for 40-45 minutes in the chamber. After removing the tube from the chamber, the time of capillary action (T) was recorded and it was multiplied with the capillary tube constant.

**TABLE II**

RESULTS OF KINEMATIC VISCOMETER BATH (JAYANTI SCIENTIFIC INSTRUMENTS)

S. No.	SAMPLE	Tube const.	T/factor (sec)	Viscosity
1.	Oil No.1	0.87	53	46.11
2.	Oil No. 2	1.23	112	137.76
3.	Oil No. 3	0.92	117	107.64
4.	Oil No. 4	0.87	17	14.79

### C. RDE-OES

In RDE-OES technique, the engine oil was placed under the effects of high potential applied to the electrodes for plasma discharge. The discharge produces the collision energy interactions among the atoms and molecules which excite them to their higher excited states or transition levels. Thus, the atomic lines can be emitted as the photons from different energy level having different wavelength and detected by detectors with charged coupled array detector. The spectra were recorded by the instrument (Spectroil model: Oil-L, No. 6253/10 manufacturer for COFMOW).

### D. LIBS

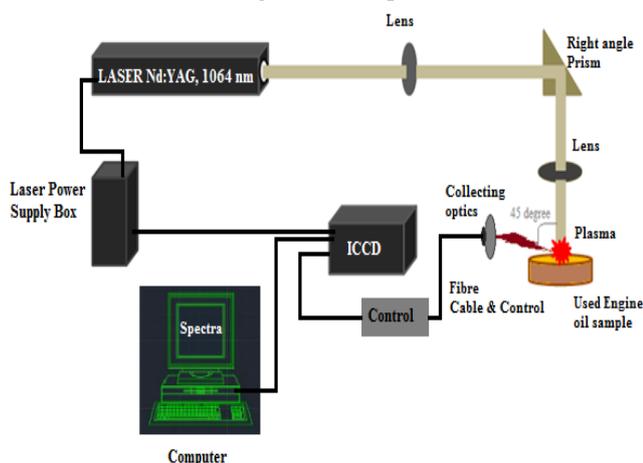
The LIBS experiment was set-up to investigate the elemental composition of the engine oil samples. The collected engine oil samples were placed for LIBS studies and the sample plate was firmly attached. The Nd:YAG Laser from Quantel Brilliant was used for designing the LIBS experiment on engine oils with Laser pulse width of 6ns. The Nd:YAG laser can be used on different laser harmonics such as 1064nm, 532nm and 355nm. For the LIBS experiment on engine oils wavelength 1064nm with pulse energy of 50mJ and repetition rate 1Hz was used. The higher repetition rate can ignite the fire so to avoid the combustion of fuel, lower repetition rate of laser should be chosen. The intense laser pulses were focused on to the surface of engine oils kept in a patridish. The laser beam was focused by the optic arrangement called beam expander with the optics of 2 inch diameter fused silica convex lens of focal length 30 cm. After folding the laser beam by prism type optics at 90 degree, the intense laser beam pulses were focused by 1 inch diameter fused silica plano convex length of focal length 10 mm that makes the focal spot of size 72  $\mu\text{m}$  and power density  $2 \times 10^{11} \text{ W/cm}^2$ . The LIBS plasma can thus be collected from the surface of engine oils using lens integrated with a fiber optics coupled to the ICCD spectrometer. The optical fiber with core diameter of 400 $\mu\text{m}$  was used to collect signal with the spectrograph ANDOR coupled with the Integrated ICCD detector used by cherry et al on LIBS on grease [5].

The ICCD was synchronized with the laser control

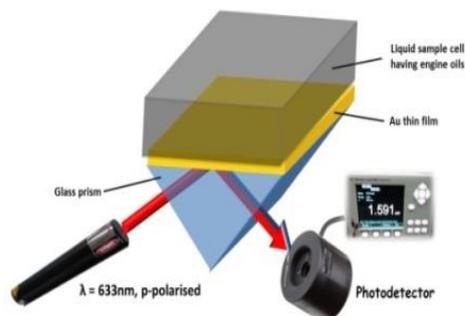
and the Q-switch pulses i.e. the triggered output from laser was fed to ICCD spectrograph. The spectrograph was used by employing the delay of 1 $\mu$ s and gate width of 20 $\mu$ s to record the plasma continuum emission consisting of atomic, elemental transitions from emission of single shot of Nd:YAG pulsed laser at 1Hz. The average LIBS spectra signal of plasma emission from engine oils was used using grating of 1800 line/mm between 200-700 nm. The analysis of LIBS spectra was performed offline by using Plasus-specline software by matching the spectral results from the NIST database provided in software and other published data on the elemental analysis.

**E. SPR**

A schematic used for studying the optical properties of engine oils using SPR technique is shown in figure 2. The thermal evaporation technique was used to deposit thin gold film of thickness 40nm on the surface of the right angled BK7 glass prism which was used for SPR studies for used engine oils. A specially designed liquid sample cell made of glass was prepared and attached to the prism by index matching liquid. The liquid sample cell was attached to the prism such that the Au thin film would remain in direct contact with liquid media for studying the degradation analysis of engine oils. SPR reflectance data were measured for prism/Au/oil sample systems for analysing the contamination in the engine oil samples [14].



**Fig. 1** Schematic of LIBS



**Fig. 2** Schematic of SPR studies

**RESULTS AND DISCUSSION**

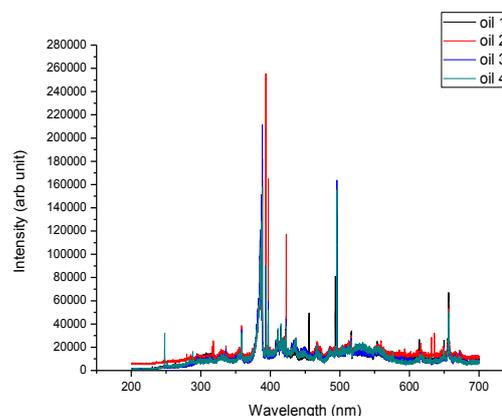
According to water content analysis, it was found that there was no water content present in all four samples and the results are presented in the Table I. Through water

content measurements, the presence of no water ensures that the degradation in the waste engine oils would be because of the wear elements from the engine parts. The detailed kinematic viscometric bath calculations and the observed studies are presented in Table II which indicates that the viscosity of different waste engine oils with respect to the engine oil from different company type. The estimated quantification of impurity elements in the engine oils were identified using RDE-OES technique. The four samples collected when investigated, the presence of impurities elemental lines in parts per million (ppm) were obtained such as lead (Pb), Aluminium (Al), Copper (Cu), Silicon (Si), Iron (Fe), Chromium (Cr), Sodium (Na), and Barium (Ba). Firstly, elemental quantitative analysis of engine oil samples were analyzed by the RDE-OES and the presence of impurity elements are presented in Table III. RDE-OES results show that the engine oil sample no. 1 sample no. 2 and sample no.3 comprises the impurity elements such as Si, Fe and Na. Some traces of aluminum were found in sample no. 3 and sample no.4. Sample no. 4 was the most degraded which consisted impurity elements such as Pb, Cu, Cr and B. The presence of lead indicates the high degradation in engine oil sample no. 4. which can cause the chronic damage to the machinery parts and the results are presented in Table III.

**TABLE III**

ELEMENTAL COMPOSITION OF ENGINE OILS USING RDE-OES IN PPM

SAMPLE	Pb	Al	Cu	Si	Fe	Cr	Na	B
Oil No. 1	0	0	0	4	1	0	5	0
Oil No. 2	0	0	0	5	2	0	6	0
Oil No. 3	0	1	0	1	2	0	5	0
Oil No. 4	22	28	44	78	327	5	26	1



**Fig. 3** LIBS spectrum of four engine oils

Similar elemental studies were cross examined by LIBS plasma based studies in which opaque plasma following the local thermal equilibrium condition consisting the atoms, ions and neutrals of all the impurity elements and the emission signals were captured by the spectrometer for the elemental detection. The LIBS spectra shown in figure 3 were obtained by the plasma formation on the samples by the triggered Q-switched laser pulses and the emission signals measured by the ICCD spectrometer. The elemental impurity lines were further analyzed by plasus-specline software and the maximum intensity lines corresponding to various impurity elements showed that impurity elements.

The impurities of Fe, Si, Al and Cu were found in the LIBS spectra of engine oil sample no. 1. The impurity lines such as Fe, Cr, Si, Al and Cu were found in engine oil samples such as engine oil sample nos. 2. Some impurities of lead were found in engine oil sample nos. 3 and 4 other than Fe, Si, Al and Cu. The estimated results from LIBS studies on engine oil samples are tabulated in Table IV.

For the reflectance plot measurement of SPR technique, wavelength  $\lambda = 633\text{nm}$  was used for the excitation on samples in angular mode interrogation mode for prism/Au/air system.

SPR measurements confirm the sensitive analysis of the degradation with the change in resonance position and the changes occur in the wave vector of resonance angle due to the change in the refractive index. The used engine oils samples consists various complex constituents such as contaminants in the form of additives and wear particles which are responsible of changing the optical properties of the Lubricants like color, transparency, refractive index and absorbance.

The comparative and detailed SPR based studies on engine oils was demonstrated by Aghayan et al. which was more sensitive and accurate as compared to other fundamental techniques such as TAN, TBN, blotter test and water content measurement [15]. The absorption of surface plasmons due to the introduction of contaminants in engine oils leads to a noticeable change in resonance angle ( $\theta_{\text{SPR}}$ ) and reflectivity minimum ( $R_{\text{min}}$ ) which is presented in figure 4. For the prism/Au/air system, reflectance (R) was found to decrease significantly and reach a minimum value of about  $R_{\text{min}} \sim 0.66$  at an incident resonance angle,  $\theta_{\text{SPR}} \sim 43.0^\circ$ . Introduction of impurities in the engine oils causes change in color, transparency, and the absorption of light which leads to the change in the relative angular shift in the position of the minimum SPR. The SPR reflectance curve showed a shift towards higher angle on replacing the air media with the oil samples (i.e. prism/Au/oil sample system) and the minimum reflectance drastically increased to  $R_{\text{min}} \sim 0.89$  at  $\theta_{\text{SPR}} \sim 47.3^\circ$  for engine oil sample no. 1. On replacing the oil sample no. 1 with other samples, the reflectance minimum SPR dip was examined to be continuously shifting towards higher angles and the graphs are presented in figure 4. The maximum shift in  $R_{\text{min}}$  and  $\theta_{\text{SPR}}$  was observed for engine oil sample no.4 which shows that the maximum contamination. The best fitted theoretical reflectance curves of SPR phenomenon are shown by solid lines in figure 4 using Fresnel's equations. The SPR reflectance data was fitted for prism/Au/air system and the value of dielectric constant for Au thin film at  $\lambda = 633\text{nm}$  was estimated by fitting the SPR reflectance data which was found to be about  $\epsilon_1 = -12.2+i1.51$ . The obtained value of complex dielectric constant of Au was close to the corresponding reported value in literature ( $-12.8+i2.7$ ). In order to determine the complex dielectric constant and refractive index of engine oil samples. Now, keeping the dielectric constant of Au thin film constant and the SPR reflectance graphs for prism/Au/oil sample system were fitted.

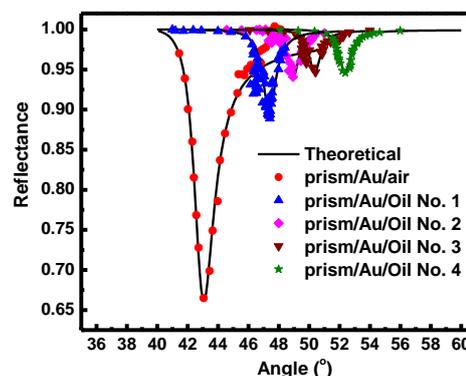


Fig. 4: SPR reflectance curves obtained for four engine oils in Kretschmann configuration

TABLE 4(A)  
ELEMENTAL IMPURITIES IN ENGINE OIL 1 FROM LIBS

Elements	Wavelength
Fe	248.007, 305.052, 311.077, 315.982, 323.513, 326.564, 336.564, 336.142, 337.88, 338.962, 358.505, 359.084, 376.966, 377.391, 380.48, 380.944, 382.18, 384.343, 385.192, 385.192, 385.579, 386.235, 387.201, 388.398, 391.449, 393.496, 394.809, 396.972, 400.023, 400.796, 407.902, 410.065, 411.108, 415.356, 416.824, 418.137, 419.798, 421.69, 422.81, 422.81, 434.358, 436.907, 439.727, 443.666, 444.361, 445.983, 446.64, 449.073, 455.523, 471.512, 473.637, 490.09, 493.527, 495.844, 507.006, 511.718, 516.584, 518.4, 518.4, 525.236, 528.248, 539.603, 553.661, 563.626, 566.677, 568.677, 568.029, 576.95, 585.486, 589.116, 601.437, 614.298, 622.563, 623.876, 649.791, 652.572, 656.434, 658.443, 664.043
Si	305.0072, 323.4517, 385.3665, 385.6018, 386.2595, 418.335, 419.813, 444.4116, 518.525, 566.6677, 568.144, 614.2487, 623.9614, 652.6609, 658.3707, 664.0618
Al	358.6557, 384.2016, 388.4353, 394.8724, 400.9583, 416.8462, 448.987, 489.891, 528.3733, 576.9137, 585.376, 622.619, 358.6557
Cu	315.8673, 323.5706, 338.0712, 339.0668, 359.2352, 377.2526, 380.5227, 382.0875, 386.046, 387.2768, 388.4131, 391.2491, 393.3268, 399.8369, 400.6165, 408.0509, 411.1296, 415.3623, 417.9512, 419.8656, 421.6912, 444.4831, 490.1427, 493.7221, 518.3367, 525.0524, 539.7295, 553.505, 563.7155, 614.2956, 622.3715, 656.4501, 658.3458, 664.1396, 315.789, 318.2172, 382.6921, 384.9582, 386.046

TABLE 4(B)  
ELEMENTAL IMPURITIES IN ENGINE OIL 2

Elements	Wavelength
Fe	248.007, 315.943, 318.067, 336.142, 358.505, 382.836, 385.115, 385.501, 386.158, 387.201, 388.359, 391.256, 393.496, 394.886, 396.972, 411.069, 414.429, 415.317, 416.824, 418.06, 419.72, 421.69, 422.81, 430.81, 430.38, 43.826, 436.946, 469.813, 473.65, 495.844, 512.838, 512.838, 516.584, 552.155, 559.223, 616.345, 631.909, 636.003, 643.998, 656.357
Cr	318.0286, 334.334, 344.144, 347.297, 387.7963, 396.9743, 399.5788, 407.486, 435.1755, 463.1606, 480.5254, 567.5257,
Si	385.6018, 386.2595,
Al	387.0049, 391.2362, 394.8724,
Cu	387.2768, 388.4131, 391.2491, 393.3268, 394.6945,

TABLE 4(C)  
ELEMENTAL IMPURITIES IN ENGINE OIL 3

Elements	Wavelength
<b>Fe</b>	247.968, 261.216, 297.829, 307.524, 336.104, 358.505, 374.61, 380.326, 382.218, 384.42, 385.154, 385.154, 385.501, 386.235, 387.201, 388.359, 391.449, 393.496, 394.886, 397.011, 410.953, 414.661, 415.317, 416.785, 417.326, 418.098, 419.798, 421.729, 422.81, 434.011, 436.444, 437.1, 438.104, 444.207, 449.343, 467.187, 469.852, 471.474, 473.753, 493.488, 495.844, 512.954, 516.507, 536.745, 541.302, 563.626, 610.397, 648.865, 656.319, 680.38
<b>Si</b>	385.6018, 386.2595, 419.813, 467.3256, 541.3099
<b>Al</b>	358.6557, 384.2328, 387.0049, 388.4353, 394.8724, 416.8462, 422.6816, 422.6816, 610.3764
<b>Pb</b>	415.282, 416.8033
<b>Cu</b>	297.8287, 374.539, 380.1556, 382.0875, 384.9582, 386.046, 387.2768, 388.4131, 391.2491, 393.268, 394.6945, 411.1296, 415.3623, 417.1851, 417.9512, 419.8656, 421.6912, 436.537, 444.0883, 467.1702, 469.747, 512.7702, 516.3251, 536.8383, 563.7155, 610.5746, 656.4501

TABLE 4(D)  
ELEMENTAL IMPURITIES IN ENGINE OIL 4

Elements	Wavelength
<b>Fe</b>	247.968, 251.753, 269.056, 272.107, 288.29, 295.358, 321.118, 358.505, 359.045, 364.839, 367.31, 378.356, 378.858, 382.682, 384.188, 385.154, 385.463, 386.235, 387.162, 388.359, 393.496, 394.886, 397.011, 400.1, 403.499, 408.25, 413.386, 414.622, 415.279, 416.862, 418.098, 419.682, 421.651, 422.81, 423.737, 425.591, 434.319, 434.667, 435.594, 435.98, 437.023, 442.739, 445.443, 446.061, 449.961, 452.24, 457.879, 467.264, 469.736, 471.474, 473.675, 483.562, 493.45, 495.844, 501.483, 503.337, 506.774, 510.945, 511.37, 512.761, 514.151, 516.584, 522.378, 539.217, 542.886, 554.597, 556.056, 565.055, 565.527, 568.531, 570.655, 576.371, 587.34, 602.711, 628.897, 656.396, 672.115, 680.457, 681.153, 691.156
<b>Si</b>	251.6112, 288.1577, 385.6018, 386.046, 386.2595, 403.5278, 419.813, 467.3256, 539.3146, 542.892, 691.1748
<b>Al</b>	272.0916, 384.2328, 387.0049, 388.4353, 388.4131, 394.8724, 403.4882, 408.4003, 416.8462, 422.6816, 423.7541, 434.7785, 435.5031, 467.1702, 570.4874
<b>Cu</b>	268.93, 272.1677, 288.4196, 288.1577, 384.9582, 393.3268, 394.6945, 408.0509, 415.3623, 417.9512, 419.8656, 421.6912, 425.5635, 435.4626, 469.747, 483.6799, 501.6629, 503.4254, 506.7094, 510.8334, 511.1915, 512.7702, 539.1656, 556.0573, 565.6629, 628.8696, 656.4501, 680.6216
<b>Pb</b>	415.282, 416.8033,

TABLE V  
COMPLEX DIELECTRIC CONSTANT AND REFRACTIVE INDEX VALUE OF ENGINE OILS

S. No.	Sample	Complex dielectric constant	Complex refractive index
1.	Oil No.1	1.805+0.01i	1.343+0.001i
2.	Oil No. 2	1.834+0.02i	1.354+0.002i
3.	Oil No. 3	1.889+0.03i	1.374+0.003i
4.	Oil No. 4	1.929+0.03i	1.388+0.003i

The recorded graphs of SPR on used engine oils samples, complex dielectric constant and refractive index was calculated. The results have been tabulated by fitting the SPR data using Fresnel equations results are presented in Table V. Table V shows that the SPR resonance angle ( $\theta_{SPR}$ ) is directly related to the real part of dielectric constant ( $\epsilon'$ ) and hence refractive index (n) which shows that FWHM of

SPR curve clearly affects the variation of imaginary part of dielectric constant ( $\epsilon''$ ) and hence extinction coefficient (k). In the present studies on engine oils, four used engine oils samples were studied and the maximum dielectric constant and refractive index was obtained for engine oil sample no. 4 as 1.929+0.031i.

### CONCLUSION

The engine oil samples were tested and examined for the impurities to evaluate the degradation of the tested samples. The optical methods like RDE-OES and LIBS have been studied to characterize the engine oil samples in terms of the impurities composition and degradation feature. The estimated results through RDE-OES and LIBS studies ensures the engine oil sample number 4 with maximum impurity elements mark the probabilistic evaluation of the damaged machinery parts. Using optical analysis of SPR measurements, engine oil sample no. 4 was found to have highest dielectric constant and refractive index resulting in maximum contamination. Thus the applications of three optical methods have been validated for the degradation analysis of engine oil samples.

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# Non-existence of perfect 2-error correcting Lee codes of word length 7 over $\mathbb{Z}$

*Catarina Cruz and Ana Breda* \*

## Abstract

The Golomb-Welch conjecture states that there is no perfect  $r$ -error correcting Lee code of word length  $n$  over  $\mathbb{Z}$  for  $n \geq 3$  and  $r \geq 2$ . This problem has received great attention due to its importance in applications in several areas beyond mathematics and computer sciences. Here, we give a contribution for the proof of the Golomb-Welch conjecture which reinforces it, proving the non-existence of perfect 2-error correcting Lee codes of word length 7 over  $\mathbb{Z}$ .

Perfect Lee codes, Golomb-Welch conjecture, tilings, Lee metric.

## 1 Introduction

Tiling problems are common in coding theory, in fact, certain tilings can be seen as error correcting codes, see [7] and [10]. Here, we are interested in dealing with tilings of spaces by Lee spheres. The study of these tilings was introduced by Golomb and Welch ([6] and [7]) which related them with error correcting codes, considering the center of a Lee sphere as a codeword and the other elements of the sphere as words which are decoded by the central codeword. When a Lee sphere of radius  $r$  tiles the  $n$ -dimensional space, the set of all centers of the Lee spheres, that is, the set of all codewords, produces a perfect  $r$ -error correcting Lee code of word length  $n$ . There exists an extensive literature on codes in the Lee metric due to their several applications, see, for instance, [1] and [2].

Golomb and Welch have conjectured that there is no perfect  $r$ -error correcting Lee code of word length  $n$  over  $\mathbb{Z}$  for  $n \geq 3$  and  $r \geq 2$ . Many partial results on this subject have been achieved. In [4] we present a proof of the Golomb-Welch conjecture for the case  $n = 7$  and  $r = 2$ , one of the cases of the conjecture that has resisted for a long time. Later, Kim [9] has proved the non-existence of perfect 2-error correcting Lee codes for a certain values of  $n$ , including  $n = 7$ . Our idea to prove the case  $n = 7$  and  $r = 2$  of the Golomb-Welch conjecture differs to the one presented in [9]. While Kim [9] has used an algebraic process, our method is faithful to the geometric idea of the problem. In our strategy we were faced with a huge amount of hypotheses to try to cover certain words

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by codewords, being the hard work of the proof. The proof is very extensive, and so, we present here only its generic idea as well as some key proofs of the achieved results, showing the line of reasoning. It should be pointed out that all proofs can be conferred in [4].

## 2 Definitions and previous results

Let  $(\mathcal{S}, \mu)$  be a metric space, where  $\mathcal{S}$  is a nonempty set and  $\mu$  a metric on  $\mathcal{S}$ . Any subset  $\mathcal{M}$  of  $\mathcal{S}$  satisfying  $|\mathcal{M}| \geq 2$  is a **code**. The elements of  $\mathcal{S}$  are called **words** and, in particular, the elements of a code  $\mathcal{M}$  are called **codewords**. A sphere centered at  $W \in \mathcal{S}$  with radius  $r$ , will be denoted by  $S(W, r)$ . If  $W \in \mathcal{M}$  and  $V \in S(W, r)$ , with  $V \neq W$ , then we say that **the codeword  $W$  covers the word  $V$** .

**Definition 1.** *A code  $\mathcal{M}$  is a **perfect  $r$ -error correcting code** if:*

- i)  $S(W, r) \cap S(V, r) = \emptyset$  for any two distinct codewords  $W$  and  $V$  in  $\mathcal{M}$ ;*
- ii)  $\bigcup_{W \in \mathcal{M}} S(W, r) = \mathcal{S}$ .*

Here, we deal with metric spaces  $(\mathbb{Z}^n, \mu_L)$ , where  $\mathbb{Z}^n$  is the  $n$ -fold Cartesian product of the set of the integer numbers, with  $n$  a positive integer number, and  $\mu_L$  is the **Lee metric**. If  $\mathcal{M} \subset \mathbb{Z}^n$  is a perfect  $r$ -error correcting code of  $(\mathbb{Z}^n, \mu_L)$ , then  $\mathcal{M}$  is called a **perfect  $r$ -error correcting Lee code of word length  $n$  over  $\mathbb{Z}$** , shortly a **PL( $n, r$ ) code**.

Having in mind the Golomb-Welch conjecture, we intend to prove the non-existence of PL(7, 2) codes. Our strategy is based on the assumption of their existence. Let us assume the existence of a PL(7, 2) code  $\mathcal{M} \subset \mathbb{Z}^7$ , and suppose, without loss of generality, that  $O \in \mathcal{M}$ , with  $O = (0, \dots, 0)$ . Thus, all words  $W \in \mathbb{Z}^7$  such that  $\mu_L(W, O) \leq 2$  are covered by the codeword  $O$ . Taking into account Definition 1, for each word  $W \in \mathbb{Z}^7$  satisfying  $\mu_L(W, O) = 3$  there exists a unique codeword  $V \in \mathcal{M}$  such that  $\mu_L(W, V) \leq 2$ , where  $V$  is such that  $\mu_L(V, O) = 5$ . We focus our attention on these codewords, being our idea mostly based in cardinality restrictions on sets of these codewords. This strategy is a natural adaptation of the one given by Horak [8] and follows the same notation.

The words  $W \in \mathbb{Z}^7$  satisfying  $\mu_L(W, O) = 3$  are of types  $[\pm 3]$ ,  $[\pm 2, \pm 1]$  and  $[\pm 1^3]$ . Note that, for instance,  $V = (v_1, \dots, v_7)$  is a word of type  $[\pm 2, \pm 1]$ , if  $|v_i| = 2$  and  $|v_j| = 1$  for some  $i, j \in \{1, \dots, 7\}$ , and  $|v_k| = 0$  for all  $k \in \{1, \dots, 7\} \setminus \{i, j\}$ . We denote by  $\mathcal{A}$ ,  $\mathcal{B}$ ,  $\mathcal{C}$ ,  $\mathcal{D}$ ,  $\mathcal{E}$ ,  $\mathcal{F}$  and  $\mathcal{G}$  the sets of codewords  $W$  satisfying  $\mu_L(W, O) = 5$  of types  $[\pm 5]$ ,  $[\pm 4, \pm 1]$ ,  $[\pm 3, \pm 2]$ ,  $[\pm 3, \pm 1^2]$ ,  $[\pm 2^2, \pm 1]$ ,  $[\pm 2, \pm 1^3]$  and  $[\pm 1^5]$ , respectively. Note that:  $[\pm 3]$  must be covered by codewords of  $\mathcal{A} \cup \mathcal{B} \cup \mathcal{C} \cup \mathcal{D}$ ;  $[\pm 2, \pm 1]$  must be covered by codewords of  $\mathcal{B} \cup \mathcal{C} \cup \mathcal{D} \cup \mathcal{E} \cup \mathcal{F}$ ;  $[\pm 1^3]$  must be covered by codewords of  $\mathcal{D} \cup \mathcal{E} \cup \mathcal{F} \cup \mathcal{G}$ . The conditions for the existence of PL(7, 2) codes derive essentially from the analysis of the cardinality of subsets of  $\mathcal{A} \cup \mathcal{B} \cup \mathcal{C} \cup \mathcal{D} \cup \mathcal{E} \cup \mathcal{F} \cup \mathcal{G}$ , in particular, of their **index subsets**.

Let  $\mathcal{I} = \{+1, +2, \dots, +7, -1, -2, \dots, -7\}$  be the **set of signed coordinates**. By index subsets of  $\mathcal{H} \subset \mathbb{Z}^7$  we consider, for  $i, j \in \mathcal{I}$ , with  $|i| \neq |j|$ , and  $k$  a positive integer number, the sets:  $\mathcal{H}_i = \{W \in \mathcal{H} : iw_{|i|} > 0\}$ ;  $\mathcal{H}_{ij} = \{W \in \mathcal{H} : iw_{|i|} > 0 \wedge jw_{|j|} > 0\}$ ;  $\mathcal{H}_i^{(k)} = \{W \in \mathcal{H} : iw_{|i|} > 0 \wedge |w_{|i|}| = k\}$ .

Next, we present some necessary conditions for the existence of PL(7, 2) codes proved in [5].

**Lemma 1.** For each  $i \in \mathcal{I}$ ,  $|\mathcal{A}_i \cup \mathcal{B}_i^{(4)} \cup \mathcal{C}_i^{(3)} \cup \mathcal{D}_i^{(3)}| = 1$ .

**Lemma 2.** For each  $i, j \in \mathcal{I}$ , with  $|i| \neq |j|$ ,

$$|\mathcal{B}_i^{(4)} \cap \mathcal{B}_j^{(1)}| + |\mathcal{C}_i \cap \mathcal{C}_j| + |\mathcal{D}_i^{(3)} \cap \mathcal{D}_j^{(1)}| + |\mathcal{E}_i^{(2)} \cap \mathcal{E}_j| + |\mathcal{F}_i^{(2)} \cap \mathcal{F}_j^{(1)}| = 1.$$

**Lemma 3.** For each  $i, j, k \in \mathcal{I}$ ,  $|\mathcal{D}_{ijk} \cup \mathcal{E}_{ijk} \cup \mathcal{F}_{ijk} \cup \mathcal{G}_{ijk}| = 1$ , with  $|i|, |j|$  and  $|k|$  pairwise distinct.

Horak [8] has deduced the following results, one of them involving the parameters  $a = |\mathcal{A}|$ ,  $b = |\mathcal{B}|$ ,  $c = |\mathcal{C}|$ ,  $d = |\mathcal{D}|$ ,  $e = |\mathcal{E}|$ ,  $f = |\mathcal{F}|$  and  $g = |\mathcal{G}|$ .

**Proposition 1.** The parameters  $a, b, c, d, e, f$  and  $g$  satisfy the system of equations

$$\begin{cases} a + b + c + d = 14 \\ b + 2c + 2d + 4e + 3f = 168 \\ d + e + 4f + 10g = 280. \end{cases}$$

**Lemma 4.** For each  $i \in \mathcal{I}$ ,  $|\mathcal{D}_i \cup \mathcal{E}_i| + 3|\mathcal{F}_i| + 6|\mathcal{G}_i| = 60$ . Consequently,  $|\mathcal{D}_i \cup \mathcal{E}_i| \equiv 0 \pmod{3}$ .

**Lemma 5.** For each  $i, j \in \mathcal{I}$ ,  $|i| \neq |j|$ ,  $|\mathcal{D}_{ij} \cup \mathcal{E}_{ij}| + 2|\mathcal{F}_{ij}| + 3|\mathcal{G}_{ij}| = 10$ .

Next results impose conditions in subsets of  $\mathcal{F}$ . The first one is derived from Lemmas 3 and 5. The proof of the second one can be conferred in [4].

**Lemma 6.** For any  $i, j \in \mathcal{I}$ , with  $|i| \neq |j|$ ,  $|\mathcal{F}_{ij}| \leq 5$ . Furthermore, if  $|\mathcal{F}_{ij}| = 5$ , then  $|\mathcal{F}_{ijk}| = 1$  for all  $k \in \mathcal{I} \setminus \{i, -i, j, -j\}$ .

**Lemma 7.** For each  $i \in \mathcal{I}$ ,  $|\mathcal{F}_i^{(2)}| \leq 4$ . If  $|\mathcal{F}_i^{(2)}| = 4$ , then  $|\mathcal{F}_i^{(2)} \cap \mathcal{F}_j| = 1$  for all  $j \in \mathcal{I} \setminus \{i, -i\}$ .

Our aim is to prove that any nonnegative integer solutions of the system of equations presented in Proposition 1 contradicts the definition of PL(7,2) code. In this sense, particular attention will be given to the sets  $\mathcal{G}$  and  $\mathcal{F}$  in which the codewords have more nonzero coordinates. In [3] and [5] we have proved:

**Theorem 1.** For each  $i \in \mathcal{I}$ ,  $3 \leq |\mathcal{G}_i| \leq 7$ .

Next, are presented conditions that must be satisfied when  $|\mathcal{G}_i|$  assumes one of the possible values for some  $i \in \mathcal{I}$ . The proofs can be checked in [4].

**Lemma 8.** *If  $|\mathcal{G}_i| = 3$ ,  $i \in \mathcal{I}$ , then  $|\mathcal{A}_i| = 1$ ,  $|\mathcal{B}_i \cup \mathcal{C}_i \cup \mathcal{E}_i| = 0$ ,  $|\mathcal{D}_i| = 3$  and  $|\mathcal{F}_i| = 13$ . More precisely,  $|\mathcal{D}_i^{(3)}| = 0$ ,  $|\mathcal{D}_i^{(1)}| = 3$ ,  $|\mathcal{F}_i^{(2)}| = 4$  and  $|\mathcal{F}_i^{(1)}| = 9$ .*

**Lemma 9.** *If  $|\mathcal{G}_i| = 4$ ,  $i \in \mathcal{I}$ , then one and only one of the following conditions must occur: i)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 3$  and  $|\mathcal{F}_i| = 11$ ; ii)  $|\mathcal{D}_i| = 6$ ,  $|\mathcal{E}_i| = 0$  and  $|\mathcal{F}_i| = 10$ . Besides, if ii) is satisfied, then  $|\mathcal{A}_i| = 1$ ,  $|\mathcal{B}_i \cup \mathcal{C}_i| = 0$ ,  $|\mathcal{D}_i^{(1)}| = 6$ ,  $|\mathcal{F}_i^{(2)}| = 4$  and  $|\mathcal{F}_i^{(1)}| = 6$ .*

**Lemma 10.** *If  $|\mathcal{G}_i| = 5$ ,  $i \in \mathcal{I}$ , then one and only one of the following conditions must occur: i)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 0$  and  $|\mathcal{F}_i| = 10$ ; ii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 3$  and  $|\mathcal{F}_i| = 9$ ; iii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 6$ ,  $|\mathcal{F}_i| = 8$  and  $|\mathcal{D}_i| \geq 3$ ; iv)  $|\mathcal{D}_i| = 9$ ,  $|\mathcal{E}_i| = 0$  and  $|\mathcal{F}_i| = 7$ . Besides, if iv) is satisfied, then  $|\mathcal{A}_i| = 1$ ,  $|\mathcal{B}_i \cup \mathcal{C}_i| = 0$ ,  $|\mathcal{D}_i^{(1)}| = 9$ ,  $|\mathcal{F}_i^{(2)}| = 4$  and  $|\mathcal{F}_i^{(1)}| = 3$ .*

**Lemma 11.** *If  $|\mathcal{G}_i| = 6$ ,  $i \in \mathcal{I}$ , then one and only one of the following conditions must occur: i)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 0$  and  $|\mathcal{F}_i| = 8$ ; ii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 3$  and  $|\mathcal{F}_i| = 7$ ; iii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 6$  and  $|\mathcal{F}_i| = 6$ ; iv)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 9$ ,  $|\mathcal{F}_i| = 5$  and  $|\mathcal{D}_i| \geq 6$ ; v)  $|\mathcal{D}_i| = 12$ ,  $|\mathcal{E}_i| = 0$  and  $|\mathcal{F}_i| = 4$ . Besides, if v) is satisfied, then  $|\mathcal{A}_i| = 1$ ,  $|\mathcal{B}_i \cup \mathcal{C}_i| = 0$ ,  $|\mathcal{D}_i^{(1)}| = 12$  and  $|\mathcal{F}_i^{(2)}| = 4$ .*

**Lemma 12.** *If  $|\mathcal{G}_i| = 7$ ,  $i \in \mathcal{I}$ , then one and only one of the following conditions must occur: i)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 3$  and  $|\mathcal{F}_i| = 5$ ; ii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 6$  and  $|\mathcal{F}_i| = 4$ ; iii)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 9$ ,  $|\mathcal{F}_i| = 3$  and  $|\mathcal{D}_i| \geq 3$ ; iv)  $|\mathcal{D}_i \cup \mathcal{E}_i| = 12$ ,  $|\mathcal{F}_i| = 2$  and  $|\mathcal{D}_i| \geq 9$ .*

**Lemma 13.** *Let  $\mathcal{G}_i$  for  $i \in \mathcal{I}$ . For all  $j \in \mathcal{I} \setminus \{i, -i\}$ ,  $|\mathcal{G}_{ij}| \leq 3$ . If  $|\mathcal{G}_{ij}| = 3$  for some  $j \in \mathcal{I} \setminus \{i, -i\}$ , then  $|\mathcal{F}_i^{(2)}| \leq 3$ . Besides: i)  $|\mathcal{G}_i| \neq 3$ ; ii) if  $|\mathcal{G}_i| = 4$ , then  $|\mathcal{F}_i| = 11$ ; iii) if  $|\mathcal{G}_i| = 5$ , then  $8 \leq |\mathcal{F}_i| \leq 10$ ; iv) if  $|\mathcal{G}_i| = 6$ , then  $5 \leq |\mathcal{F}_i| \leq 8$ .*

Theorem 1 restricts the variation of  $g = |\mathcal{G}|$ . Since  $g = \frac{1}{5} \sum_{i \in \mathcal{I}} |\mathcal{G}_i|$ , with  $|\mathcal{I}| = 14$ , and by Theorem 1,  $3 \leq |\mathcal{G}_i| \leq 7$ , for all  $i \in \mathcal{I}$ , then  $9 \leq g \leq 19$ . Our strategy to prove the non-existence of PL(7, 2) codes relies on restricting more and more the variation of  $|\mathcal{G}_i|$ , for any  $i \in \mathcal{I}$ .

### 3 Proof of $|\mathcal{G}_i| \neq 3$ for any $i \in \mathcal{I}$

In this section we present the general idea of the proof of  $|\mathcal{G}_i| \neq 3$  for any  $i \in \mathcal{I}$ . Under the assumption  $|\mathcal{G}_i| = 3$ , for some  $i \in \mathcal{I}$ , we derive conditions that necessarily must be satisfied by the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$  and which will lead to contradictions in the definition of PL(7, 2) code.

Let us suppose  $|\mathcal{G}_i| = 3$  for some  $i \in \mathcal{I}$ . Under this condition, by Lemma 8, we have  $|\mathcal{F}_i| = 13$  and, in particular,  $|\mathcal{F}_i^{(2)}| = 4$ . The following results impose conditions in the index distribution of the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$ .

**Proposition 2.** *If  $|\mathcal{G}_i| = 3$ , for some  $i \in \mathcal{I}$ , then there are  $\alpha, \beta, \gamma$  in  $\mathcal{I} \setminus \{i, -i\}$ , with  $\alpha, \beta$  and  $\gamma$  pairwise distinct, such that,  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$ . Furthermore,  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .*

*Proof.* Let  $i \in \mathcal{I}$  be such that  $|\mathcal{G}_i| = 3$ . The three codewords  $W_1, W_2, W_3$  of  $\mathcal{G}_i$  satisfy  $W_1 \in \mathcal{G}_{iw_1w_2w_3w_4}$ ,  $W_2 \in \mathcal{G}_{iw_5w_6w_7w_8}$  and  $W_3 \in \mathcal{G}_{iw_9w_{10}w_{11}w_{12}}$ , with  $w_1, \dots, w_{12} \in \mathcal{I} \setminus \{i, -i\}$  and not necessarily pairwise distinct.

As  $|\mathcal{F}_i| = \frac{1}{3} \sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\omega}|$  and  $|\mathcal{F}_i| = 13$  one has,

$$\sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\omega}| = 39. \quad (3.1)$$

Since  $|\mathcal{I} \setminus \{i, -i\}| = 12$  and, by Lemma 5,  $|\mathcal{F}_{i\omega}| \leq 5$  for all  $\omega \in \mathcal{I} \setminus \{i, -i\}$ , the equation (3.1) implies the existence of, at least, two elements  $\alpha, \beta \in \mathcal{I} \setminus \{i, -i\}$ , with  $\alpha \neq \beta$ , such that,  $|\mathcal{F}_{i\alpha}|, |\mathcal{F}_{i\beta}| \geq 4$ .

Let us show, now, that there are, at most, three elements  $\alpha, \beta, \gamma \in \mathcal{I} \setminus \{i, -i\}$ , distinct between them, such that,  $|\mathcal{F}_{i\alpha}|, |\mathcal{F}_{i\beta}|, |\mathcal{F}_{i\gamma}| \geq 4$ . Suppose, by contradiction, that there exist  $\alpha, \beta, \gamma, \delta \in \mathcal{I} \setminus \{i, -i\}$ , distinct between them, such that,  $|\mathcal{F}_{i\alpha}|, |\mathcal{F}_{i\beta}|, |\mathcal{F}_{i\gamma}|, |\mathcal{F}_{i\delta}| \geq 4$ . By Lemma 5,  $|\mathcal{G}_{i\alpha}| = |\mathcal{G}_{i\beta}| = |\mathcal{G}_{i\gamma}| = |\mathcal{G}_{i\delta}| = 0$  and having in account the index distribution of  $W_1, W_2, W_3 \in \mathcal{G}_i$ , we may conclude that  $w_1, \dots, w_{12} \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma, \delta\}$ . As  $|\mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma, \delta\}| = 8$ , there are  $\omega, \theta \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma, \delta\}$  such that  $|\mathcal{G}_{i\omega\theta}| \geq 2$ , contradicting Lemma 3. Thus, there are, at most, three distinct elements  $\alpha, \beta, \gamma \in \mathcal{I} \setminus \{i, -i\}$  satisfying  $|\mathcal{F}_{i\alpha}|, |\mathcal{F}_{i\beta}|, |\mathcal{F}_{i\gamma}| \geq 4$ .

Next, we prove that there is no  $\omega \in \mathcal{I} \setminus \{i, -i\}$  satisfying  $|\mathcal{F}_{i\omega}| = 4$ . By contradiction, assume that  $\alpha \in \mathcal{I} \setminus \{i, -i\}$  is such that  $|\mathcal{F}_{i\alpha}| = 4$ .

In view of (3.1) and in spite of the conditions established until now, one and only one of the following conditions is verified:

- i) there is  $\beta \in \mathcal{I} \setminus \{i, -i, \alpha\}$  such that  $|\mathcal{F}_{i\beta}| = 5$  and  $|\mathcal{F}_{i\omega}| = 3$  for any  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta\}$ ;
- ii) there are  $\beta, \gamma \in \mathcal{I} \setminus \{i, -i, \alpha\}$ , with  $\beta \neq \gamma$ , such that  $|\mathcal{F}_{i\beta}|, |\mathcal{F}_{i\gamma}| \geq 4$  and  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .

As  $|\mathcal{G}_i| = 3$  and  $|\mathcal{G}_i| = \frac{1}{4} \sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\omega}|$ , then  $\sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\omega}| = 12$ .

Let us analyze the hypothesis i). By Lemma 5,  $|\mathcal{G}_{i\alpha}| = |\mathcal{G}_{i\beta}| = 0$  and  $|\mathcal{G}_{i\omega}| \leq 1$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta\}$ . As  $|\mathcal{I} \setminus \{i, -i, \alpha, \beta\}| = 10$ , it follows that  $\sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\omega}| \leq 10$ , which is a contradiction.

Now assume that the conditions stated in ii) are fulfilled. In these conditions,  $|\mathcal{F}_{i\alpha}| + |\mathcal{F}_{i\beta}| + |\mathcal{F}_{i\gamma}| \leq 14$ , then having in consideration (3.1) we get  $\sum_{\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}} |\mathcal{F}_{i\omega}| \geq 25$ . Since  $|\mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}| = 9$  and  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ , then  $|\mathcal{F}_{i\omega}| \geq 1$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ , furthermore, there are, at most, two distinct elements  $\theta, \theta' \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$  so that  $1 \leq |\mathcal{F}_{i\theta}|, |\mathcal{F}_{i\theta'}| \leq 2$ . Thus, by Lemma 5,  $\sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\omega}| \leq 11$ , contradicting our assumption.

Accordingly:

- there are exactly two distinct elements  $\alpha, \beta \in \mathcal{I} \setminus \{i, -i\}$  so that  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = 5$  and  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta\}$ ;

- there are exactly three distinct elements  $\alpha, \beta, \gamma \in \mathcal{I} \setminus \{i, -i\}$  such that  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$  and  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .

Let us assume first that there are only two distinct elements  $\alpha, \beta \in \mathcal{I} \setminus \{i, -i\}$  such that  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = 5$ . By (3.1), there exists a unique element  $\theta \in \mathcal{I} \setminus \{i, -i, \alpha, \beta\}$  such that  $|\mathcal{F}_{i\theta}| = 2$  and  $|\mathcal{F}_{i\omega}| = 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \theta\}$ . Consequently, by Lemma 5, we conclude that  $\sum_{\omega \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\omega}| \leq 11$ , which is a contradiction.

Summarizing, if  $|\mathcal{G}_i| = 3$ , there are exactly three distinct elements  $\alpha, \beta, \gamma$  in  $\mathcal{I} \setminus \{i, -i\}$ , such that,  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$  and  $|\mathcal{F}_{i\omega}| \leq 3$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .  $\square$

**Proposition 3.** *Let  $\alpha, \beta, \gamma \in \mathcal{I} \setminus \{i, -i\}$  such that  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$ . Then,  $|\alpha|, |\beta|$  and  $|\gamma|$  are pairwise distinct and there exist  $U_1, U_2, U_3, U_4 \in \mathcal{F}_i$  whose index distributions satisfy:*

$U_1$	$i$	$\alpha$	$\beta$	$x_1$
$U_2$	$i$	$\alpha$	$\gamma$	$x_2$
$U_3$	$i$	$\beta$	$\gamma$	$x_3$
$U_4$	$i$	$y_1$	$y_2$	$y_3$

where  $x_1, x_2, x_3, y_1, y_2, y_3 \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .

*Proof.* Let  $\alpha, \beta, \gamma \in \mathcal{I} \setminus \{i, -i\}$  so that  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$ . Let us assume, by contradiction, that  $|\alpha|, |\beta|$  and  $|\gamma|$  are not pairwise distinct. Without loss of generality we may assume that  $\alpha = -\beta$ . Thus,  $\mathcal{F}_{i\alpha} \cap \mathcal{F}_{i\beta} = \emptyset$  and, consequently,  $|\mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta}| = 10$ . As  $|\mathcal{F}_i| = 13$ , then  $|\mathcal{F}_{i\alpha\gamma}| = |\mathcal{F}_{i\beta\gamma}| = 1$  and so  $\mathcal{F}_i = \mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma}$ . From Lemma 8,  $|\mathcal{F}_i^{(2)}| = 4$ . That is,  $|\mathcal{F}_i^{(2)} \cap (\mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma})| = 4$ . Consequently, there exists  $\omega \in \{\alpha, \beta, \gamma\}$  such that  $|\mathcal{F}_i^{(2)} \cap \mathcal{F}_{i\omega}| \geq 2$ , contradicting Lemma 7. Therefore,  $|\alpha|, |\beta|$  and  $|\gamma|$  are pairwise distinct.

We have just seen that if  $\mathcal{F}_i = \mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma}$ , then Lemma 7 is contradicted. Thus,  $\mathcal{F}_i \supset \mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma}$  which implies  $|\mathcal{F}_{i\alpha\beta\gamma}| = 0$ . As  $|\mathcal{F}_{i\omega}| = 5$  for all  $\omega \in \{\alpha, \beta, \gamma\}$ , by Lemma 6 we get  $|\mathcal{F}_{i\omega u}| = 1$  for all  $u \in \mathcal{I} \setminus \{i, -i, \omega, -\omega\}$ . As a consequence,  $|\mathcal{F}_{i\alpha\beta}| = |\mathcal{F}_{i\alpha\gamma}| = |\mathcal{F}_{i\beta\gamma}| = 1$ . That is, there are  $U_1, U_2, U_3 \in \mathcal{F}_i$  satisfying:

$U_1$	$i$	$\alpha$	$\beta$	$x_1$
$U_2$	$i$	$\alpha$	$\gamma$	$x_2$
$U_3$	$i$	$\beta$	$\gamma$	$x_3$

Tab. 1: Partial index distribution of  $U_1, U_2, U_3 \in \mathcal{F}_i$ .

where  $x_1, x_2, x_3 \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ . As  $|\mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma}| = 12$  and  $|\mathcal{F}_i| = 13$ , there exists  $U_4 \notin \mathcal{F}_{i\alpha} \cup \mathcal{F}_{i\beta} \cup \mathcal{F}_{i\gamma}$ , that is,  $U_4 \in \mathcal{F}_{iy_1y_2y_3}$  where  $y_1, y_2, y_3 \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$ .  $\square$

Next results are proved in [4] and characterize partially the codewords of the sets  $\mathcal{F}_i^{(2)}$  and  $\mathcal{G}_i$ , respectively.

**Corollary 1.** *In the considered conditions  $\mathcal{F}_i^{(2)} = \{U_4, U', U'', U'''\}$ , where  $U' \in \mathcal{F}_{i\alpha} \setminus (\mathcal{F}_\beta \cup \mathcal{F}_\gamma)$ ,  $U'' \in \mathcal{F}_{i\beta} \setminus (\mathcal{F}_\alpha \cup \mathcal{F}_\gamma)$  and  $U''' \in \mathcal{F}_{i\gamma} \setminus (\mathcal{F}_\alpha \cup \mathcal{F}_\beta)$ .*

**Proposition 4.** *If  $|\mathcal{F}_{i\alpha}| = |\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 5$ , then  $|\mathcal{G}_{i\alpha}| = |\mathcal{G}_{i\beta}| = |\mathcal{G}_{i\gamma}| = 0$ . Furthermore, there are  $\delta, \varepsilon, \theta \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$  so that  $|\mathcal{G}_{i\delta}| = |\mathcal{G}_{i\varepsilon}| = |\mathcal{G}_{i\theta}| = 2$  and  $|\mathcal{G}_{i\omega}| = 1$  for all  $\omega \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma, \delta, \varepsilon, \theta\}$ . The index distributions of the three codewords  $W_1, W_2, W_3 \in \mathcal{G}_i$  satisfy:*

$W_1$	$i$	$\delta$	$\varepsilon$	$w_1$	$w_2$
$W_2$	$i$	$\delta$	$\theta$	$w_3$	$w_4$
$W_3$	$i$	$\varepsilon$	$\theta$	$w_5$	$w_6$

where  $\delta, \varepsilon, \theta, w_1, \dots, w_6 \in \mathcal{I} \setminus \{i, -i, \alpha, \beta, \gamma\}$  are pairwise distinct.

Let us consider

$$\mathcal{I} = \{i, -i, j, -j, k, -k, l, -l, m, -m, n, -n, o, -o\}.$$

Since the index distribution of  $U_1, U_2, U_3, U_4 \in \mathcal{F}_i$  is the one illustrated in Proposition 3, we may assume, without loss of generality, that  $\alpha = j$ ,  $\beta = k$  and  $U_1 \in \mathcal{F}_{ijkl}$ , that is:

$U_1$	$i$	$j$	$k$	$l$
$U_2$	$i$	$j$	$\gamma$	$x_1$
$U_3$	$i$	$k$	$\gamma$	$x_2$
$U_4$	$i$	$y_1$	$y_2$	$y_3$

Tab. 2: Partial index distribution of  $U_1, \dots, U_4 \in \mathcal{F}_i$ .

where  $x_1, x_2 \in \mathcal{I} \setminus \{i, -i, j, k, \gamma, l\}$  and  $y_1, y_2, y_3 \in \mathcal{I} \setminus \{i, -i, j, k, \gamma\}$ .

In what follows, the index distribution of the codewords of  $\mathcal{G}_i$  and  $U_1, U_2, U_3, U_4$  codewords of  $\mathcal{F}_i$  are the ones given in Proposition 4 and Table 2, respectively. Next results, proved in [4], allow us to analyze how the codewords of  $\mathcal{G}_i$  and  $\mathcal{F}_i$  fit together.

**Proposition 5.** *If  $l \neq \delta, \varepsilon, \theta$ , then, without loss of generality,  $W_1 \in \mathcal{G}_{i\delta\varepsilon l}$ , and either  $\theta = -l$  or  $\theta = -j$  or  $\theta = -k$ .*

**Proposition 6.**  *$U_4 \in \mathcal{F}_{iy_1y_2y_3}$  for  $y_1, y_2, y_3 \in \{-j, -k, -\gamma, l, x_1, x_2\}$ , where  $x_1$  and  $x_2$  are such that  $U_2 \in \mathcal{F}_{ij\gamma x_1}$  and  $U_3 \in \mathcal{F}_{ik\gamma x_2}$  (see Table 2).*

**Proposition 7.** *If  $|\mathcal{G}_{i\omega}| = 2$  for some  $\omega \in \mathcal{I} \setminus \{i, -i, j, -j, k, -k, \gamma, -\gamma, l\}$ , then either  $\omega = x_1$  or  $\omega = x_2$ .*

**Proposition 8.** *The indices  $\delta, \varepsilon, \theta \in \{-j, -k, -\gamma, l, x_1, x_2\} \setminus \{y_1, y_2, y_3\}$  furthermore  $|\{-j, -k, -\gamma, l, x_1, x_2\}| = 6$ .*

We have characterized the partial index distributions of the codewords of  $\mathcal{G}_i$  and the codewords  $U_1, U_2, U_3, U_4 \in \mathcal{F}_i$ . From this characterization we can get the complete index distribution of all codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$  which apparently do not contradict the definition of PL(7,2) code. There exist only two possible index distributions, however, considering other elements  $\omega \in \mathcal{I} \setminus \{i\}$ , analyzing the complete index distribution of all codewords of  $\mathcal{G}_\omega \cup \mathcal{F}_\omega$ , we conclude that is not possible to describe the set  $\mathcal{G} \cup \mathcal{F}$  without superposition between codewords. This analysis is extensive and can be checked in [4].

#### 4 Proof of $|\mathcal{G}_i| \neq 4$ for any $i \in \mathcal{I}$

Here, we restrict even more the range of variation of  $|\mathcal{G}_i|$  for any  $i \in \mathcal{I}$ . Such as in the previous section, we assume, without loss of generality, that there exists an  $i \in \mathcal{I}$  such that  $|\mathcal{G}_i| = 4$ . We focus our attention on the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$  and deduce some necessary conditions which must be satisfied by them.

Let  $i \in \mathcal{I}$  be so that  $|\mathcal{G}_i| = 4$ , by Lemma 9,  $10 \leq |\mathcal{F}_i| \leq 11$ . The first result characterize the partial index distribution of the four codewords of  $\mathcal{G}_i$ .

**Proposition 9.** *If  $|\mathcal{G}_i| = 4$ , for  $i \in \mathcal{I}$ , then  $|\mathcal{G}_{i\alpha}| \leq 2$  for any  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ .*

*Proof.* By Lemma 5 we know that  $|\mathcal{G}_{i\alpha}| \leq 3$  for all  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ . Suppose, by contradiction, that  $j \in \mathcal{I} \setminus \{i, -i\}$  is such that  $|\mathcal{G}_{ij}| = 3$ .

As  $|\mathcal{G}_i| = 4$ , from Lemma 9 it follows that  $|\mathcal{F}_i| = 10$  or  $|\mathcal{F}_i| = 11$ . Next, we analyze, separately, these two hypotheses:  $|\mathcal{F}_i| = 10$  and  $|\mathcal{F}_i| = 11$ .

Suppose first that  $|\mathcal{F}_i| = 10$ . Then, by Lemma 9,  $|\mathcal{B}_i \cup \mathcal{C}_i \cup \mathcal{E}_i| = 0$ . Considering Lemma 5 and taking into account that, by hypothesis,  $|\mathcal{G}_{ij}| = 3$ , then  $|\mathcal{D}_{ij} \cup \mathcal{E}_{ij}| + 2|\mathcal{F}_{ij}| = 1$ . Since  $|\mathcal{E}_i| = 0$ , it follows that  $|\mathcal{D}_{ij}| = 1$  and  $|\mathcal{F}_{ij}| = 0$ .

Let us consider two words  $V_1 = (v_{11}, v_{12}, \dots, v_{17})$  and  $V_2 = (v_{21}, v_{22}, \dots, v_{27})$  such that  $|v_{1i}| = 2$ ,  $|v_{1j}| = 1$ ,  $|v_{2i}| = 1$  and  $|v_{2j}| = 2$ . These words must be covered by codewords of  $\mathcal{B}_{ij} \cup \mathcal{C}_{ij} \cup \mathcal{D}_{ij} \cup \mathcal{E}_{ij} \cup \mathcal{F}_{ij}$ . As  $|\mathcal{B}_{ij}| = |\mathcal{C}_{ij}| = |\mathcal{E}_{ij}| = |\mathcal{F}_{ij}| = 0$ , then  $V_1$  and  $V_2$  must be covered by the unique codeword in  $\mathcal{D}_{ij}$ , which is not possible since the codewords of  $\mathcal{D}$  are of type  $[\pm 3, \pm 1^2]$ .

Now assume that  $|\mathcal{F}_i| = 11$ . Since we are under the assumption  $|\mathcal{G}_{ij}| = 3$ , let us consider  $W_1, W_2, W_3 \in \mathcal{G}_{ij}$  such that  $W_1 \in \mathcal{G}_{ijw_1w_2w_3}$ ,  $W_2 \in \mathcal{G}_{ijw_4w_5w_6}$  and  $W_3 \in \mathcal{G}_{ijw_7w_8w_9}$ , with  $w_1, \dots, w_9 \in \mathcal{I} \setminus \{i, -i, j, -j\}$ . We note that, by Lemma 3,  $w_1, \dots, w_9$  must be pairwise distinct. As  $|\mathcal{G}_i| = 4$ , let  $W_4 \in \mathcal{G}_i \setminus \mathcal{G}_j$  so that  $W_4 \in \mathcal{G}_{iw_{10}w_{11}w_{12}w_{13}}$ , where  $w_{10}, w_{11}, w_{12}, w_{13} \in \mathcal{I} \setminus \{i, -i, j\}$ . In Table 3, the codewords  $W_1, \dots, W_4 \in \mathcal{G}_i$  are schematically represented.

Since  $w_1, \dots, w_9 \subset \mathcal{I} \setminus \{i, -i, j, -j\}$  with  $w_1, \dots, w_9$  pairwise distinct, taking into account that  $|\mathcal{I}| = 14$ , let  $\{\beta\} = \mathcal{I} \setminus \{i, -i, j, -j, w_1, \dots, w_9\}$ . Note that,  $\mathcal{I} \setminus \{i, -i\} = \{j\} \cup \{-j\} \cup \{\beta\} \cup \{w_1, \dots, w_9\}$ . Considering  $W_4 \in \mathcal{G}_{iw_{10}w_{11}w_{12}w_{13}}$ ,  $w_{10}, \dots, w_{13} \in \mathcal{I} \setminus \{i, -i, j\}$ , we conclude that  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| \geq 2$ . On the other hand,  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| \leq 3$ , otherwise Lemma 3 is contradicted. Consider the cases: *i*)  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| = 2$ ; *ii*)  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| = 3$ .

Suppose that  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| = 2$ , in these conditions  $W_4 \in \mathcal{G}_{i,-j,\beta,w_{10},w_{11}}$ , with  $w_{10}, w_{11} \in \{w_1, \dots, w_9\}$ . Accordingly, we have

$W_1$	$i$	$j$	$w_1$	$w_2$	$w_3$
$W_2$	$i$	$j$	$w_4$	$w_5$	$w_6$
$W_3$	$i$	$j$	$w_7$	$w_8$	$w_9$
$W_4$	$i$	$w_{10}$	$w_{11}$	$w_{12}$	$w_{13}$

 Tab. 3: Partial index distribution of the codewords of  $\mathcal{G}_i$ .

$|\mathcal{G}_{ij}| = 3$ ,  $|\mathcal{G}_{iw_{10}}| = |\mathcal{G}_{iw_{11}}| = 2$  and  $|\mathcal{G}_{iw}| = 1$  for all  $w \in \mathcal{I} \setminus \{i, -i, j, w_{10}, w_{11}\}$ . Consequently, from Lemma 5 it follows that  $|\mathcal{F}_{ij}| = 0$ ,  $|\mathcal{F}_{iw_{10}}|, |\mathcal{F}_{iw_{11}}| \leq 2$  and  $|\mathcal{F}_{iw}| \leq 3$  for all  $w \in \mathcal{I} \setminus \{i, -i, j, w_{10}, w_{11}\}$ . As  $|\mathcal{F}_i| = \frac{1}{3} \sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}|$  and we are assuming  $|\mathcal{F}_i| = 11$ , then  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}| = 33$ . However, taking into account what was been said before,  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}| \leq 31$ , which is a contradiction.

Now consider that  $|\{w_{10}, \dots, w_{13}\} \cap \{w_1, \dots, w_9\}| = 3$ . Thus, we have  $W_4 \in \mathcal{G}_{ixw_{10}w_{11}w_{12}}$ , with  $x \in \{-j, \beta\}$  and  $w_{10}, w_{11}, w_{12} \in \{w_1, \dots, w_9\}$ . In these conditions,  $|\mathcal{G}_{ij}| = 3$ ,  $|\mathcal{G}_{iw_{10}}| = |\mathcal{G}_{iw_{11}}| = |\mathcal{G}_{iw_{12}}| = 2$ ,  $|\mathcal{G}_{iy}| = 0$  for  $\{y\} = \{-j, \beta\} \setminus \{x\}$  and  $|\mathcal{G}_{iw}| = 1$  for all  $w \in \mathcal{I} \setminus \{i, -i, j, y, w_{10}, w_{11}, w_{12}\}$ . Consequently, by Lemma 5, we get  $|\mathcal{F}_{ij}| = 0$ ,  $|\mathcal{F}_{iw_{10}}|, |\mathcal{F}_{iw_{11}}|, |\mathcal{F}_{iw_{12}}| \leq 2$ ,  $|\mathcal{F}_{iy}| \leq 5$  and  $|\mathcal{F}_{iw}| \leq 3$  for all  $w \in \mathcal{I} \setminus \{i, -i, j, y, w_{10}, w_{11}, w_{12}\}$ . Accordingly,  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}| \leq 32$ , obtaining again a contradiction.  $\square$

We have just proved that for any  $\alpha \in \mathcal{I} \setminus \{i, -i\}$  we get  $|\mathcal{G}_{i\alpha}| \leq 2$ . Let us consider the subset  $\mathcal{J} \subset \mathcal{I} \setminus \{i, -i\}$  so that:  $\mathcal{J} = \{\alpha \in \mathcal{I} \setminus \{i, -i\} : |\mathcal{G}_{i\alpha}| = 2\}$ . The following result, proved in [4], restricts the variation of  $|\mathcal{J}|$ .

**Proposition 10.** *The cardinality of  $\mathcal{J}$  satisfies  $4 \leq |\mathcal{J}| \leq 6$ .*

Next, we establish conditions which must be verified by the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$  when  $|\mathcal{J}|$  assumes each one of the possible values.

**Proposition 11.** *If  $|\mathcal{J}| = 4$ , then  $|\mathcal{G}_{i\alpha}| = 1$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  and  $|\mathcal{F}_i| = 10$ .*

*Proof.* By assumption  $|\mathcal{G}_i| = 4$ , consequently  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{G}_{i\alpha}| = 16$ . That is,  $\sum_{\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})} |\mathcal{G}_{i\alpha}| + \sum_{\alpha \in \mathcal{J}} |\mathcal{G}_{i\alpha}| = 16$ . As  $|\mathcal{G}_{i\alpha}| = 2$  for all  $\alpha \in \mathcal{J}$  and, by assumption,  $|\mathcal{J}| = 4$ , it follows that  $\sum_{\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})} |\mathcal{G}_{i\alpha}| = 8$ . Taking into account Proposition 9,  $|\mathcal{G}_{i\alpha}| \leq 1$  for all  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$ . Since that  $|\mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})| = 8$ , we must impose  $|\mathcal{G}_{i\alpha}| = 1$  for all  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$ .

From Lemma 9 we know that  $|\mathcal{F}_i| = 10$  or  $|\mathcal{F}_i| = 11$ . Let us suppose that  $|\mathcal{F}_i| = 11$ . In these conditions, taking into account that  $|\mathcal{F}_i| = \frac{1}{3} \sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}|$ , we have  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}| = 33$ . Having in mind what was proved before, from Lemma 5, we get  $|\mathcal{F}_{i\alpha}| \leq 2$  for all  $\alpha \in \mathcal{J}$  and  $|\mathcal{F}_{i\alpha}| \leq 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$ . That is,  $\sum_{\alpha \in \mathcal{I} \setminus \{i, -i\}} |\mathcal{F}_{i\alpha}| \leq 32$ , which is an absurdity. Therefore,  $|\mathcal{F}_i| = 10$ .  $\square$

Next, following a similar reasoning, we derive equivalent results whose proofs can be checked in [4].

**Proposition 12.** *If  $|\mathcal{J}| = 4$ , with  $\mathcal{J} = \{\beta, \gamma, \delta, \varepsilon\}$ , then  $|\mathcal{F}_{i\alpha}| \geq 1$  for all  $\alpha \in \mathcal{I} \setminus \{i, -i\}$  and there exist, at least, two elements  $\alpha \in \mathcal{J}$  such that  $|\mathcal{F}_{i\alpha}| = 2$ . Furthermore:*

- i) if  $\beta, \gamma \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 2$ , then  $|\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = 1$  and  $|\mathcal{F}_{i\alpha}| = 3$  for all  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$ ;*
- ii) if  $\beta, \gamma, \delta \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  which satisfy  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = 2$ , then  $|\mathcal{F}_{i\varepsilon}| = 1$  and there are seven elements  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  such that  $|\mathcal{F}_{i\alpha}| = 3$ ;*
- iii) if  $|\mathcal{F}_{i\alpha}| = 2$  for all  $\alpha \in \mathcal{J}$ , then there are, at least, six elements  $\alpha \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  satisfying  $|\mathcal{F}_{i\alpha}| = 3$ .*

**Proposition 13.** *If  $|\mathcal{J}| = 5$ , there exists  $x \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  so that  $|\mathcal{G}_{ix}| = 0$ . Furthermore,  $|\mathcal{G}_{i\alpha}| = 1$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ .*

Since by Lemma 9 we have  $|\mathcal{F}_i| = 11$  or  $|\mathcal{F}_i| = 10$ , the following two propositions give us conditions for the index distribution of the codewords of  $\mathcal{F}_i$  when  $|\mathcal{J}| = 5$  and  $|\mathcal{F}_i|$  assumes each one of these values.

**Proposition 14.** *Let  $|\mathcal{J}| = 5$  and  $x \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  be such that  $|\mathcal{G}_{ix}| = 0$ . If  $|\mathcal{F}_i| = 11$ , then:  $|\mathcal{F}_{i\alpha}| = 2$  for any  $\alpha \in \mathcal{J}$ ;  $|\mathcal{F}_{ix}| = 5$ ;  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ .*

**Proposition 15.** *Let  $|\mathcal{J}| = 5$ , with  $\mathcal{J} = \{\beta, \gamma, \delta, \varepsilon, \theta\}$ , and  $x \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  such that  $|\mathcal{G}_{ix}| = 0$ . If  $|\mathcal{F}_i| = 10$ , then there are, at least, two elements  $\alpha \in \mathcal{J}$  such that  $|\mathcal{F}_{i\alpha}| = 2$ . Furthermore:*

- i) if  $\beta, \gamma \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = 2$ , then  $|\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = |\mathcal{F}_{i\theta}| = 1$ ,  $|\mathcal{F}_{ix}| = 5$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;*
- ii) if  $\beta, \gamma, \delta \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  which satisfy  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = 2$ , then one of the following conditions must occur:  $|\mathcal{F}_{ix}| = 5$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, five elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 4$ ,  $|\mathcal{F}_{i\varepsilon}| = |\mathcal{F}_{i\theta}| = 1$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;*
- iii) if  $\beta, \gamma, \delta, \varepsilon \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = 2$ , then one of the following conditions must occur:  $|\mathcal{F}_{ix}| = 5$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, four elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 4$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, five elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 3$ ,  $|\mathcal{F}_{i\theta}| = 1$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;*
- iv) if  $|\mathcal{F}_{i\alpha}| = 2$  for any  $\alpha \in \mathcal{J}$ , then one of the following conditions must occur:  $|\mathcal{F}_{ix}| = 5$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, three elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 4$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, four elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 3$  and  $|\mathcal{F}_{i\alpha}| = 3$  for, at least, five elements  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ ;  $|\mathcal{F}_{ix}| = 2$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x\} \cup \mathcal{J})$ .*

**Proposition 16.** *If  $|\mathcal{J}| = 6$ , then there exist  $x, y \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  such that  $|\mathcal{G}_{ix}| = |\mathcal{G}_{iy}| = 0$ . Furthermore,  $|\mathcal{G}_{i\alpha}| = 1$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ .*

**Proposition 17.** *Let  $|\mathcal{J}| = 6$ , with  $\mathcal{J} = \{\beta, \gamma, \delta, \varepsilon, \theta, \mu\}$ , and  $x, y \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  such that  $|\mathcal{G}_{ix}| = |\mathcal{G}_{iy}| = 0$ . If  $|\mathcal{F}_i| = 11$ , then there are, at least, five elements  $\alpha \in \mathcal{J}$  satisfying  $|\mathcal{F}_{i\alpha}| = 2$ . Furthermore, if there exist exactly five elements in these conditions, then:  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = |\mathcal{F}_{i\theta}| = 2$ ;  $|\mathcal{F}_{i\mu}| = 1$ ;  $|\mathcal{F}_{ix}| = |\mathcal{F}_{iy}| = 5$ ;  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ .*

**Proposition 18.** *Let  $|\mathcal{J}| = 6$ , with  $\mathcal{J} = \{\beta, \gamma, \delta, \varepsilon, \theta, \mu\}$ , and  $x, y \in \mathcal{I} \setminus (\{i, -i\} \cup \mathcal{J})$  be such that  $|\mathcal{G}_{ix}| = |\mathcal{G}_{iy}| = 0$ . If  $|\mathcal{F}_i| = 10$ , then there are, at least, three elements  $\alpha \in \mathcal{J}$  satisfying  $|\mathcal{F}_{i\alpha}| = 2$ . Furthermore:*

- i) *if  $\beta, \gamma, \delta \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = 2$ , then  $|\mathcal{F}_{i\varepsilon}| = |\mathcal{F}_{i\theta}| = |\mathcal{F}_{i\mu}| = 1$ ,  $|\mathcal{F}_{ix}| = 5$ ,  $|\mathcal{F}_{iy}| = 4$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ ;*
- ii) *if  $\beta, \gamma, \delta, \varepsilon \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = 2$ , then  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| \geq 8$ ; if  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| = 8$ , then  $|\mathcal{F}_{i\theta}| = |\mathcal{F}_{i\mu}| = 1$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ ;*
- iii) *if  $\beta, \gamma, \delta, \varepsilon, \theta \in \mathcal{J}$  are the unique elements in  $\mathcal{J}$  satisfying  $|\mathcal{F}_{i\beta}| = |\mathcal{F}_{i\gamma}| = |\mathcal{F}_{i\delta}| = |\mathcal{F}_{i\varepsilon}| = |\mathcal{F}_{i\theta}| = 2$ , then  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| \geq 7$ ; if  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| = 7$ , then  $|\mathcal{F}_{i\mu}| = 1$  and  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ ;*
- iv) *if  $|\mathcal{F}_{i\alpha}| = 2$  for any  $\alpha \in \mathcal{J}$ , then  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| \geq 6$ ; if  $|\mathcal{F}_{ix}| + |\mathcal{F}_{iy}| = 6$ , then  $|\mathcal{F}_{i\alpha}| = 3$  for any  $\alpha \in \mathcal{I} \setminus (\{i, -i, x, y\} \cup \mathcal{J})$ .*

From the presented results is possible to describe the index distribution of all codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$ ,  $i \in \mathcal{I}$ . The strategy applied to verify that any index distribution of such codewords contradicts the definition of PL(7, 2) code is the same referred in the last part of the Section 3 and can be conferred in [4].

## 5 Proof of $|\mathcal{G}_i| \neq 5$ for any $i \in \mathcal{I}$

Here, we analyze the hypothesis  $|\mathcal{G}_i| = 5$  for some  $i \in \mathcal{I}$ . Let us assume  $|\mathcal{G}_i| = 5$  for  $i \in \mathcal{I}$ . Since, from Lemma 5,  $|\mathcal{G}_{i\alpha}| \leq 3$  for any  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ , we distinguish the cases:

- 1)  $|\mathcal{G}_{i\alpha}| = 3$  for some  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ ;
- 2)  $|\mathcal{G}_{i\alpha}| \leq 2$  for any  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ .

For each one of these cases, we derive, initially, some conditions which will be useful for the characterization of the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$ . Here, we only present the analysis of the hypothesis 1), being the hypothesis 2) analyzed in [4].

Let us consider  $|\mathcal{G}_i| = 5$  and  $|\mathcal{G}_{ij}| = 3$  for some  $j \in \mathcal{I} \setminus \{i, -i\}$ . Then, by Lemma 10,  $7 \leq |\mathcal{F}_i| \leq 10$ . The following proposition restricts even more the variation of  $|\mathcal{F}_i|$ .

**Proposition 19.** *If  $|\mathcal{G}_i| = 5$  and  $|\mathcal{G}_{ij}| = 3$ , then  $|\mathcal{F}_{ij}| = 0$  and  $8 \leq |\mathcal{F}_i| \leq 9$ .*

*Proof.* Since  $|\mathcal{G}_{ij}| = 3$ , from Lemma 5 it follows that  $|\mathcal{D}_{ij} \cup \mathcal{E}_{ij}| + 2|\mathcal{F}_{ij}| + 9 = 10$ , implying  $|\mathcal{F}_{ij}| = 0$  and  $|\mathcal{D}_{ij} \cup \mathcal{E}_{ij}| = 1$ .

As  $|\mathcal{G}_i| = 5$  and  $|\mathcal{G}_{ij}| = 3$ , by Lemma 13 we get  $8 \leq |\mathcal{F}_i| \leq 10$ . Supposing  $|\mathcal{F}_i| = 10$ , by Lemma 4 we must impose  $|\mathcal{D}_i \cup \mathcal{E}_i| = 0$ , which contradicts  $|\mathcal{D}_{ij} \cup \mathcal{E}_{ij}| = 1$ . Therefore,  $8 \leq |\mathcal{F}_i| \leq 9$ .  $\square$

It is possible, up to an equivalent index distributions, to characterize all codewords of  $\mathcal{G}_{ij}$ , as we will see in the next proposition proved in [4].

**Proposition 20.** *The index distribution of the codewords  $W_1, W_2, W_3 \in \mathcal{G}_{ij}$  satisfies:*

$W_1$	$i$	$j$	$k$	$l$	$m$
$W_2$	$i$	$j$	$-k$	$-l$	$n$
$W_3$	$i$	$j$	$-m$	$-n$	$o$

The index distribution of the codewords of  $\mathcal{G}_{ij}$  presented in Proposition 20 induces a partition  $\mathcal{P}$  of  $\mathcal{I} \setminus \{i, -i, j\}$ :

$$\mathcal{P}_1 = \{k, l, m\}; \mathcal{P}_2 = \{-k, -l, n\}; \mathcal{P}_3 = \{-m, -n, o\}; \mathcal{P}_4 = \{-o\}; \mathcal{P}_5 = \{-j\}. \quad (5.1)$$

Let us consider the subsets of, respectively,  $\mathcal{G}_i$  and  $\mathcal{F}_i$ :

$$\mathcal{H} = \{W \in \mathcal{G}_{iw_1w_2w_3w_4} : w_1 \in \mathcal{P}_1 \wedge w_2 \in \mathcal{P}_2 \wedge w_3 \in \mathcal{P}_3 \wedge w_4 \in \{-o, -j\}\}$$

and

$$\mathcal{J} = \{U \in \mathcal{F}_{iu_1u_2u_3} : u_1 \in \mathcal{P}_1 \wedge u_2 \in \mathcal{P}_2 \wedge u_3 \in \mathcal{P}_3\}.$$

Taking into account the partition of  $\mathcal{I} \setminus \{i, -i, j\}$ , see (5.1), we get  $\mathcal{G}_i \setminus \mathcal{G}_j = \mathcal{H} \cup \mathcal{G}_{i,-o,-j}$  and  $\mathcal{F}_i = \mathcal{J} \cup \mathcal{F}_{i,-o} \cup \mathcal{F}_{i,-j}$ .

Next results, proved in [4], impose conditions on the index distribution of the codewords of  $(\mathcal{G}_i \setminus \mathcal{G}_j) \cup \mathcal{F}_i$  by the establishment of relations between the cardinality of the sets  $\mathcal{H}$ ,  $\mathcal{J}$ ,  $\mathcal{F}_{i,-o}$  and  $\mathcal{F}_{i,-j}$ . The following proposition will be useful to obtain the refereed relations.

**Proposition 21.** *The set  $\mathcal{D}_{i,j,-o} \cup \mathcal{E}_{i,j,-o}$  satisfies  $|\mathcal{D}_{i,j,-o} \cup \mathcal{E}_{i,j,-o}| = 1$ .*

**Proposition 22.** *The sets  $\mathcal{H}$  and  $\mathcal{J}$  satisfy  $|\mathcal{H} \cup \mathcal{J}| \leq 6$ . Furthermore,  $1 \leq |\mathcal{H}| \leq 2$  and  $|\mathcal{J}| \leq 5$ .*

**Proposition 23.** *If  $|\mathcal{H}| = 1$ , then  $3 \leq |\mathcal{J}| \leq 5$  and  $|\mathcal{F}_{i,-o,-j}| = 0$ . In particular, considering  $W_4 \in \mathcal{H}$  one has:*

- i) if  $W_4 \in \mathcal{G}_{i,-o}$ , then  $4 \leq |\mathcal{J}| \leq 5$ . Moreover, if  $|\mathcal{J}| = 4$ , then  $|\mathcal{F}_{i,-o}| = 1$ ,  $|\mathcal{F}_{i,-j}| = 3$  and  $|\mathcal{F}_i| = 8$ ;*

- ii) if  $W_4 \in \mathcal{G}_{i,-j}$ , then  $3 \leq |\mathcal{J}| \leq 5$ . Moreover, if  $|\mathcal{J}| = 3$ , then  $|\mathcal{F}_{i,-o}| = 3$ ,  $|\mathcal{F}_{i,-j}| = 2$  and  $|\mathcal{F}_i| = 8$ .

**Proposition 24.** *If  $|\mathcal{H}| = 2$ , then  $|\mathcal{G}_{i,-o,-j}| = 0$  and  $3 \leq |\mathcal{J}| \leq 4$ . In particular, if  $|\mathcal{J}| = 3$ , then  $|\mathcal{F}_i| = 8$  and considering  $W_4, W_5 \in \mathcal{H}$ :*

- i) if  $W_4, W_5 \in \mathcal{G}_{i,-o}$ , then either  $|\mathcal{F}_{i,-j}| = 5$ , or,  $|\mathcal{F}_{i,-j}| = 4$ ,  $|\mathcal{F}_{i,-o}| = 1$  and  $|\mathcal{F}_{i,-o,-j}| = 0$ ;
- ii) if  $W_4, W_5 \in \mathcal{G}_{i,-j}$ , then either  $|\mathcal{F}_{i,-o}| = 4$ ,  $|\mathcal{F}_{i,-j}| = 2$  and  $|\mathcal{F}_{i,-o,-j}| = 1$ , or,  $|\mathcal{F}_{i,-o}| = 4$ ,  $|\mathcal{F}_{i,-j}| = 1$  and  $|\mathcal{F}_{i,-o,-j}| = 0$ ;
- iii) if  $W_4 \in \mathcal{G}_{i,-o}$  and  $W_5 \in \mathcal{G}_{i,-j}$ , then either  $|\mathcal{F}_{i,-o}| = 3$ ,  $|\mathcal{F}_{i,-j}| = 3$  and  $|\mathcal{F}_{i,-o,-j}| = 1$ , or,  $|\mathcal{F}_{i,-o}| = 2$ ,  $|\mathcal{F}_{i,-j}| = 3$  and  $|\mathcal{F}_{i,-o,-j}| = 0$ .

The index characterization of the codewords of  $\mathcal{G}_i \cup \mathcal{F}_i$  is mostly based in Propositions 23 and 24. However, as in the previous cases, all possible index characterizations lead to contradictions, as can be conferred in [4]. The proof of  $|\mathcal{G}_i| \neq 5$  for any  $i \in \mathcal{I}$  is completed with the analysis of the condition  $|\mathcal{G}_{i\alpha}| \leq 2$  for any  $\alpha \in \mathcal{I} \setminus \{i, -i\}$ . The study of this condition can be checked in [4], where its impossibility is proved.

## 6 Conclusion of the proof of the non-existence of PL(7, 2) codes

In the previous sections we have proved that if there exists a PL(7, 2) code  $\mathcal{M}$ , then  $\mathcal{G} \subset \mathcal{M}$  is such that  $6 \leq |\mathcal{G}_i| \leq 7$  for any  $i \in \mathcal{I}$ . Here, we show that this assumption leads us to contradictions, proving thus the non-existence of PL(7, 2) codes. Under this condition we derive the following result.

**Proposition 25.** *There exists  $\alpha \in \mathcal{I}$  such that  $|\mathcal{G}_\alpha| = 7$ . Furthermore, if  $|\mathcal{G}_\alpha| = 7$ , for some  $\alpha \in \mathcal{I}$ , then there exist, at least, four elements  $\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}$  satisfying  $|\mathcal{G}_{\alpha\beta}| = 3$ .*

*Proof.* We have proved that  $6 \leq |\mathcal{G}_\alpha| \leq 7$  for any  $\alpha \in \mathcal{I}$ . We recall that

$$g = |\mathcal{G}| = \frac{1}{5} \sum_{\alpha \in \mathcal{I}} |\mathcal{G}_\alpha|. \quad (6.1)$$

Let us suppose, by contradiction, that  $|\mathcal{G}_\alpha| = 6$  for any  $\alpha \in \mathcal{I}$ . As  $|\mathcal{I}| = 14$ , by (6.1) we conclude that  $g = \frac{84}{5}$ , which it is not possible since  $g$  must be an integer number. Therefore, there exists  $\alpha \in \mathcal{I}$  such that  $|\mathcal{G}_\alpha| = 7$ .

Let  $\alpha \in \mathcal{I}$  be such that  $|\mathcal{G}_\alpha| = 7$ . We note that  $|\mathcal{G}_\alpha| = \frac{1}{4} \sum_{\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}} |\mathcal{G}_{\alpha\beta}|$ ,

that is,

$$\sum_{\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}} |\mathcal{G}_{\alpha\beta}| = 28. \quad (6.2)$$

From Lemma 5 it follows that  $|\mathcal{G}_{\alpha\beta}| \leq 3$  for any  $\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}$ . If we suppose, by contradiction, that, at most, there are three elements  $\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}$  satisfying  $|\mathcal{G}_{\alpha\beta}| = 3$ , then from (6.2) it follows that  $\sum_{\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}} |\mathcal{G}_{\alpha\beta}| \leq 27$ , facing up a contradiction. Accordingly, there are, at least, four elements  $\beta \in \mathcal{I} \setminus \{\alpha, -\alpha\}$  such that  $|\mathcal{G}_{\alpha\beta}| = 3$ .  $\square$

Consider  $\mathcal{I} = \{i, -i, j, -j, k, -k, l, -l, m, -m, n, -n, o, -o\}$ . Taking into account the previous proposition, let us assume  $|\mathcal{G}_i| = 7$  and  $|\mathcal{G}_{ij}| = 3$ . From Proposition 20 it follows that the codewords  $W_1, W_2, W_3 \in \mathcal{G}_{ij}$  satisfy the following index distribution:

$W_1$	$i$	$j$	$k$	$l$	$m$
$W_2$	$i$	$j$	$-k$	$-l$	$n$
$W_3$	$i$	$j$	$-m$	$-n$	$o$

Tab. 4: Index distribution of the codewords of  $\mathcal{G}_{ij}$ .

The index distribution of the codewords of  $\mathcal{G}_{ij}$  induces the following partition  $\mathcal{P}$  of  $\mathcal{I} \setminus \{i, -i, j\}$ :

$$\mathcal{P}_1 = \{k, l, m\}; \quad \mathcal{P}_2 = \{-k, -l, n\}; \quad \mathcal{P}_3 = \{-m, -n, o\}; \quad \mathcal{P}_4 = \{-j\}; \quad \mathcal{P}_5 = \{-o\}. \quad (6.3)$$

Having in view Proposition 25 and the partition of  $\mathcal{P}$ , next result, proved in [4], imposes conditions on the elements  $\alpha \in \mathcal{I} \setminus \{i, -i, j\}$  which satisfy  $|\mathcal{G}_{i\alpha}| = 3$ .

**Proposition 26.** *There are, at least, two elements  $\alpha, \beta \in \mathcal{P}_1 \cup \mathcal{P}_2 \cup \mathcal{P}_3$  satisfying  $|\mathcal{G}_{i\alpha}| = |\mathcal{G}_{i\beta}| = 3$ .*

By Proposition 26, let us consider  $\alpha \in \mathcal{P}_1 \cup \mathcal{P}_2 \cup \mathcal{P}_3$  such that  $|\mathcal{G}_{i\alpha}| = 3$ . Analyzing the partition  $\mathcal{P}$  of  $\mathcal{I} \setminus \{i, -i, j\}$ , see (6.3), we distinguish, without loss of generality, the hypotheses:  $\alpha = k$ ;  $\alpha = m$ ;  $\alpha = -m$ ;  $\alpha = o$ . Our aim is to characterize all possible index distributions for the codewords of  $\mathcal{G}_i$ . For that, we analyze each one of the referred hypotheses. This analysis is presented in [4] and follows the same idea described in the last part of the Section 3. For any index distribution of the codewords of  $\mathcal{G}_i$ , the description of other codewords of the set  $\mathcal{G} \cup \mathcal{F}$  implies always superposition between codewords, contradicting the definition of PL(7, 2) code. Thus, we establish the main theorem:

**Theorem 2.** *There exist no PL(7, 2) code.*

## 7 Conclusion

The Golomb-Welch conjecture states that there is no PL( $n, r$ ) code for  $n \geq 3$  and  $r \geq 2$ . Here, we reinforce the conjecture proving the non-existence of PL(7, 2) codes. The way how the proof was built reveals how difficult was to

solve the case. We have focused our attention on words which dist three units from  $O = (0, \dots, 0)$ . Actually, there exist many ways to try to cover all these words by codewords, and although we have obtained many results which restrict the number of such hypotheses, in many cases, to achieve contradictions we had to apply exhaustion methods to study a large number of cases. This was the major hard work of the proof. In some cases we have tried to use computational methods having in view a quick analysis of the many cases we had to deal with, however, it would be necessary to implement an algorithm requiring a lot of information, not being easy to do it, at least, with our knowledge.

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# Preparation of Biodegradable Methacrylic Nanoparticles by Semicontinuous Heterophase Polymerization for Drugs Loading: The Case of Acetylsalicylic Acid

J. Roberto López, Hened Saade, Graciela Morales, Javier Enríquez, Raúl G. López

**Abstract**—Implementation of systems based on nanostructures for drug delivery applications have taken relevance in recent studies focused on biomedical applications. Although there are several nanostructures as drugs carriers, the use of polymeric nanoparticles (PNP) has been widely studied for this purpose, however, the main issue for these nanostructures is the size control below 50 nm with a narrow distribution size, due to they must go through different physiological barriers and avoid to be filtered by kidneys (< 10 nm) or the spleen (> 100 nm).

Thus, considering these and other factors it can be mentioned that drug-loaded nanostructures with sizes varying between 10 and 50 nm are preferred in the development and study of PNP/drugs systems. In these sense, the Semicontinuous Heterophase Polymerization (SHP) offers the possibility to obtain PNP in the desired size range. Considering the above explained, methacrylic copolymer nanoparticles were obtained under SHP.

The reactions were carried out in a jacketed glass reactor with the required quantities of water, ammonium persulfate as initiator, sodium dodecyl sulfate/sodium dioctylsulfosuccinate as surfactants, methyl methacrylate and methacrylic acid as monomers with molar ratio of 2/1, respectively. The monomer solution was dosed dropwise during reaction at 70 °C with a mechanical stirring of 650 rpm. Nanoparticles of poly(methyl methacrylate-co-methacrylic acid) were loaded with acetylsalicylic acid (ASA, aspirin) by a chemical adsorption technique. The purified latex was put in contact with a solution of ASA in dichloromethane (DCM) at 0.1, 0.2, 0.4 or 0.6 wt-%, at 35°C during 12 hours. According to the boiling point of DCM, as well as DCM and water densities, the loading process is completed when the whole DCM is evaporated.

The hydrodynamic diameter was measured after polymerization by quasi-elastic light scattering and transmission electron microscopy, before and after loading procedures with ASA. The quantitative and qualitative analyses of PNP loaded with ASA were measured by infrared spectroscopy, differential scattering calorimetry and thermogravimetric analysis. Also, the molar mass distributions of polymers were determined in a gel permeation chromatograph apparatus. The load capacity and efficiency were determined by gravimetric analysis.

The hydrodynamic diameter results for methacrylic PNP without ASA showed a narrow distribution with an average particle size around 10 nm and a composition methyl methacrylate/methacrylic acid molar ratio equal to 2/1, same composition of Eudragit S100, which is a commercial compound widely used as excipient. Moreover, the latex was stabilized in a relative high solids content (around 11 %), a monomer conversion almost 95 % and a number molecular weight around 400 Kg/mol.

The average particle size in the PNP/aspirin systems fluctuated between 18 and 24 nm depending on the initial percentage of aspirin in the loading process, being the drug content as high as 24 % with an efficiency loading of 36 %. These average sizes results have not been reported in the literature, thus, the methacrylic nanoparticles here reported are capable to be loaded with a considerable amount of ASA and be used as a drug carrier.

**Keywords**—Aspirin, biodegradable, biocompatibility, Eudragit S100, methacrylic nanoparticles.

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# Mixed Effects Models for Short-Term Load Forecasting for the Spanish Regions: Castilla-Leon, Castilla-La Mancha and Andalucía

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**Abstract**—This paper focuses on application of linear mixed model to short-term load forecasting. The challenge of this research is to improve a currently working model at the Spanish Transport System Operator, programmed by us, and based on linear autoregressive techniques and neural networks. The forecasting system currently forecasts each of the regions within the Spanish grid separately, even though the behavior of the load in each region is affected by the same factors in a similar way. A load forecasting system has been verified in this work by using the real data from a utility. In this research it has been used an integration of several regions into a linear mixed model as starting point to obtain the information from other regions. Firstly, the systems to learn general behaviors present in all regions, and secondly, it is identified individual deviation in each region. The technique can be especially useful when modeling the effect of special days with scarce information from the past. The three most relevant regions of the system have been used to test the model, focusing on special day and improving the performance of both currently working models used as benchmark. A range of comparisons with different forecasting models has been conducted. The forecasting results demonstrate the superiority of the proposed methodology.

**Keywords**—Short-term load forecasting, mixed effects models, neural networks.

## I. INTRODUCTION

ONE of the most crucial fields of research for efficient and reliable operation of power system in last few decades is the electrical short term load forecasting. It is very important in the field of load flow analysis, contingency analysis, scheduling, maintenance and planning of power system. Many different techniques ranging from linear models to artificial intelligence methods [1]-[3] have been applied in the sort-term load forecasting (STLF). The main problems of forecasting are: shifting in consumer behavior, spreading of newer technology, changes in energy generation techniques and modification of regulation and policies. Moreover, we review STLF to improve the processing capacity of computers and the availability of more detailed load data.

The tasks for the forecasting process are:

- 1) Classification of days,
- 2) Selection and treatment of meteorological variables,
- 3) Processing of load time series,
- 4) Choice and adjustment of forecasting engine.

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Database specific are required by most of these tasks, therefore each data series may require different techniques and /or adjustments.

The forecast of special days is the specific problem of STLF. Electrical load on a particular date is affected by several socioeconomic factors such as: days adjacent or near holidays, national or regional holidays, daylight savings time, strikes... When designing a STLF model all these types of days need to be taken into account. Special days have an effect on the load profile very specific, and this is the main problem. Systems have to learn the proper behavior but there are not many samples in the training data sets from which forecast. Other problems are: if the training data are collected from too far in the past, data could be obsolete, and if the data are collected only from recent years then only very few examples of each type of special day could be used in the forecast.

STLF models have used several techniques ranging from linear regressive methods [4]-[6] to evolutionary algorithms and to more complex systems based on neural networks [7]-[14], [19]. The structure of these methods comprises a set of input variables that include temperature, past load values, type of day information coded into binary or dummy variables or other weather variables. The output can also be diverse due to others use a different model for each hour while some models predict full profiles of 24 hours with one model. In addition, some models forecast day profile and peak loads separately.

Forecast of several regions from the same system has been addressed in previous researches [15]- [17]. More suitable approach to the effect of weather was provided to obtain a more accurate forecast by. Nonetheless, forecasting them separately and by splitting the data into isolated regions, there are common behaviors among these regions that are overseen. In this research, it has been considered that the effect that holidays have on similar regions to be correlated or even equal among the regions. Furthermore, using data from all regions to train the forecasting model would increase the validity of the training.

This work is the result of a collaborative project between Red Eléctrica de España (REE) and Universidad Miguel Hernández (UMH).

Gelman and Hill [18] discussed the multilevel modeling allows to use data from all groups while still consider specific group variation. Then, linear mixed models are commonly used in these cases to provide an alternative either to isolate each region completely or to pool all data together. This partial pooling is used when data within each group is scarce but also variance is high.

This research is focused on a STLF model based on linear

mixed models. Our research team and the Spanish Transport System Operator (TSO) jointly designed a model based on linear autoregressive models and neural networks and the model in this research derives from that one. Taking into account the correlation of the effect of special days among regions some modifications are designed to improve the forecast of each region on special days. The regions considered in this study are Castilla-Leon, Castilla-La Mancha and Andalucía (orange on Fig. 1), which add up to about 51% of national area.

It is described in Section 2 the use made of linear mixed models to create the new improved model and the original load forecasting model. It is included in Section 3 the results of forecasting the whole year 2015 using the improved model and both original models based on neural networks and linear regression. In the end of the paper, the advantages of the new model and exposes the conclusions drawn from the results is discussed section 4.

## II. MATERIALS AND METHODS

### A. The original model

This research has been carried out with the collaboration from the Spanish Transport System Operator to improve their STLF system. Last two years, our research group designed a full forecasting system for the complete inland system but also for each of the 18 smaller regions that conform it. It is currently working at the TSO headquarters. It was specifically developed to reduce the forecasting error on hot days and cold, regional holidays and national, special periods like Passover and Christmas and days adjacent to holidays. This forecasting system provides a 24-hour load profile. This output is a combination of the forecasts obtained by the NARX models and the AR. Furthermore, the forecast for every hour of the day is obtained by 24 different sub-models. The input information is the same for each model. In Fig. 2 can be seen the model's data flow.

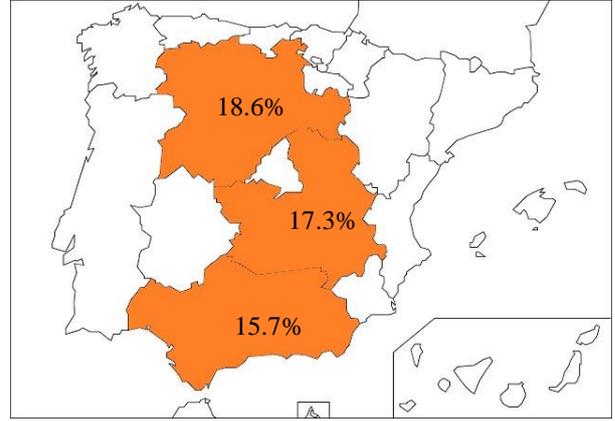


Figure 1. Total area percentage of the studied regions.

Each region is forecasted separately when applying the former structure. To conform the input vector the information used consists on:

- Meteorological data: One or more weather stations in the area are used to conform the weather variables included in the model and to forecasts temperature for each region. The concepts of hot, HDD, and cold degree days, CDD, described in the research carried out by J. R. Cancelo, A. Espasa, and R. Grafe, in their work "Forecasting the electricity load from one day to one week ahead for the Spanish system operator" International Journal of Forecasting [9] are used to process the data into each variable. Moreover, data from previous days is also included.
- Calendar data: Different day categories represent in the form of binary variables, therefore, the information about holidays is included. Two groups of categories have defined: modifiers and exclusive. Table 1 and 2 contain the description of the groups: the first one, the former, contains mutually exclusive categories, and the second one, the latter, contains categories conceived as modifiers to the first ones.
- Load data: Single hourly value are included considering the latest available data from the system.

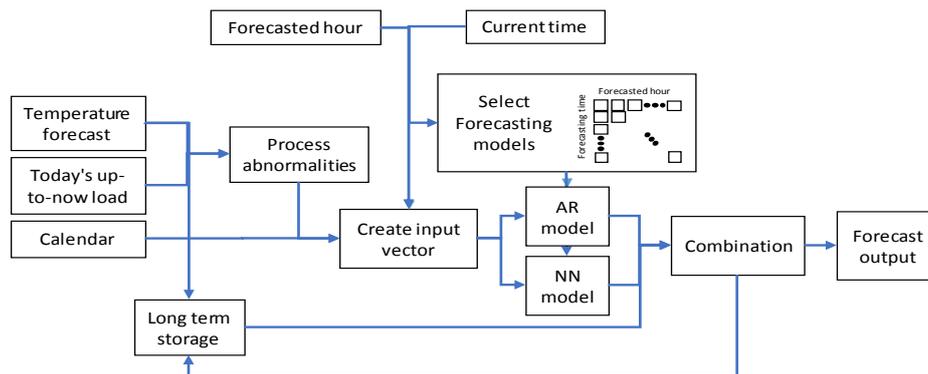


Figure 2. Flowchart of the forecasting system.

Equation 1 describes the forecasting engines used in the original model that are an autoregressive with errors and exogenous input and Equation 2 describes the nonlinear autoregressive neural network (NARX) used in this research:

$$y_t = \sum_{i=1}^p \varphi_i \cdot e_{t-i} + X_t \cdot \beta + \varepsilon_t \quad (1)$$

$$y_t = f \left( y_{t-1}, \dots, y_{t-n_y}, u_{t-1}, \dots, u_{t-n_u} \right) \quad (2)$$

where  $e_{t-i}$  is the forecast error at  $t-i$ ,  $X_t$  is the input matrix of exogenous variables,  $p$  is the number of known previous errors considered,  $\varepsilon_t$  is a random shock and  $\varphi_i$ , and  $\beta$  are coefficients calculated from the training data by a maximum likelihood method and  $u_i$  is a known input,  $n_u$  is the number of different exogenous inputs, and  $n_y$  is the number of

previous outputs fed back into the network and  $yt$  is the output.

TABLE I  
DESCRIPTION OF EXCLUSIVE VARIABLES

EXCLUSIVE VARIABLES						
NATIONAL SPECIAL DAYS		NATIONAL HOLIDAYS		BEFORE & AFTER HOLIDAY		DAY OF THE WEEK
Special days with their own specific profile.		Special days with a similar profile		Days which profile is affected by an adjacent holiday		Regular days
ALL	ONLY MON-FRI	Rest of national holidays marked at B.O.E.		BEFORE HOLIDAY	AFTER HOLIDAY	
Jan 1 <sup>st</sup> Jan 6 <sup>th</sup> May 1 <sup>st</sup> Dec 24 <sup>th</sup> Dec 25 <sup>th</sup> Dec 31 <sup>st</sup> Passover	Jan 2 <sup>nd</sup> Jan 5 <sup>th</sup> Dec 7 <sup>th</sup> Dec 26 <sup>th</sup> Dec 30 <sup>th</sup>	TYPICALLY	Aug 15 <sup>th</sup> Oct 12 <sup>th</sup> Nov 1 <sup>st</sup> Dec 6 <sup>th</sup> Dec 8 <sup>th</sup>	Only Mon-Fri	Only Mon-Thru Only Fri	Mon Tue Wed Thu Fri  Sat

Special days with their own specific profile. Special days adjacent holiday Regular days.  
with a similar profile Days which profile is affected by an

TABLE II  
DESCRIPTION OF MODIFIERS OF VARIABLES.

MODIFIERS						
CHRISTMAS			REGIONAL	AUGUST	DAYLIGHT SAVING TIME	
Days affected by Christmas period			Days affected by regional holidays	Days affected by holiday periods in August	Days affected by Daylight Savings Time	
ONLY MON-SAT	ONLY MON-FRI	ONLY SUN	Decimal number from 0 to 1.	Traditionally, vacation periods are assigned splitting August in 4 periods	Spring	Fall
Dec 20 <sup>th</sup> Dec 21 <sup>st</sup> Dec 22 <sup>nd</sup> Dec 23 <sup>rd</sup>	Dec 27 <sup>th</sup> -29 <sup>th</sup> Jan, 2 <sup>nd</sup> -5 <sup>th</sup>	Dec 26 <sup>th</sup> -30 <sup>th</sup>	Expresses the fraction of the GNP that the provinces on holiday represent.	Period 1 Period 2 Period 3 Period 4	Sunday Monday Tuesday	Sunday Monday Tuesday

B. General principles of linear mixed models

Generalizing the linear regression a linear mixed models can be obtained in which slopes and intercepts are allowed to vary by group. In other words, inner the same model, one variable may have different coefficients providing the membership of the data unit to a given group. A normal distribution usually determines the allowed variation of intercepts and slopes. The model becomes equivalent to a classical complete-pooling model when the standard deviation of the distribution is zero. On the other hand, then the model corresponds to a no-pooling model and each group is modeled independently when the deviation is infinite.

The “fixed effects” are the components of the model for which no variation among groups is accepted. On the other hand, “Random effects” are those of variables for which the coefficients for each group are obtained from a random distribution.

In the model described in equation 3, if random effects are also considered fixed effects, then fixed coefficient represent the average population while random coefficients mean zero.

$$y_i = X_i\beta + Z_i b_i + \varepsilon_i$$

$$b_i \sim N_q(0, \Psi)$$

$$\varepsilon_i \sim N_{n_i}(0, \sigma^2 \Lambda_i) \quad (3)$$

Where,  $\beta$  is the vector of fixed effects coefficients  $X_i$  is the matrix for fixed effects observations in group  $i$ ,  $b_i$  is the vector of random effects coefficients in group  $i$ ,  $Z_i$  is the matrix for random effects observations in group  $i$ ,  $\varepsilon_i$  is the vector of errors in group  $i$ ,  $\psi$  is the covariance matrix for random effects and  $\sigma^2 \Lambda$  is the covariance matrix for the errors in group  $i$ .  $y_i$  is the response vector of the  $i^{th}$  group.

C. The new model with the Fixed and random effects

The fixed and random variables used for the mixed effects model are mentioned in section 2.B. The latter allows for a variation of the coefficient among groups following a normal distribution while the former permits only one coefficient for all groups. Per contra, if we allow our model to include variables that do not show any correlation among groups there can be a third type of variables. In consequence, the coefficient can be freely chosen for each group. The suggested model selects one of these three categories to all variables that determine the characteristics of day. Inasmuch as, learning from the profiles from other regions as well as its own will allow us to model the behavior of certain days of a given region.

Next section shows how each type of day has been imputed to a category based on the empirical results. To that

end, the effect of each type of special day will be considered either group specific, group general or correlated.

### III. RESULTS

In order to test the validity of the proposed model based on mixed models the following experiments were carried out. For the three most significant regions in Spain: Madrid, Catalonia and Valencia it was forecasted the whole year 2015. The historical period from 2012 to 2014 was used to train all models. Two additional forecasts were obtained from the current models based on autoregressive linear models and an autoregressive neural network supplementary and in order to obtain a benchmark to which compare the results.

The assignment of each day category to either fixed or random or to uncorrelated coefficients is shown in Table 3.

The comparisons of these forecasts both in general and specifically to the special days in which the model has been applied are shown in the following subsections. For a better understanding of the results is also included an additional analysis of the results by time of day or by aggregate forecasting error.

TABLE III

ASSIGNMENT OF VARIABLES TO MIXED MODEL CATEGORIES

RANDOM	FIXED	UNCORRELATED
Passover	National Holidays	Christmas
National Special Days	Regional Holidays	Regular days
Before Christmas	Adjacent to Holiday August Groups DST	

#### A. General results

The overall results by pooling together all 365 days from all regions (1095 days) and grouping them by three categories of effects in the model is shown in Table 4. The use of mixed models improves the accuracy of those type of days considered to have random and fixed effects respecting the original autoregressive model as far as can be seen in the results. The NARX model presents an overall more accurate result but specifically worse on special days. Then, the mixed model is a good candidate to replace the autoregressive model. Figure 3 shows these results graphically illustrated.

Results by region are shown in Table 5. The mixed model improves the accuracy of the forecast on those days for with correspondence among zones is taking into examination, decreasing the error to 4% as it can be seen in the results.

TABLE IV  
FORECAST ERROR OF 3 REGIONS POOL.

MAPE	# DAYS	ARX	NARX	MIXED
RANDOM	25x3	3,72%	5,00%	3,54%
FIXED	54x3	5,21%	5,02%	5,05%
UNCORR.	286x3	3,63%	3,13%	3,63%
ALL	365x3	3,82%	3,48%	3,83%

TABLE V  
FORECAST ERROR BY REGION.

MAPE	# DAYS	ARX	NARX	MIXED
MADRID	RANDOM	3,01%	6,15%	2,96%
	FIXED	4,38%	5,42%	4,09%
	UNCOR.	3,40%	3,23%	3,39%
CATALONIA	RANDOM	2,77%	3,62%	2,56%
	FIXED	3,79%	4,44%	3,59%
	UNCOR.	2,56%	2,40%	2,57%
VALENCIA	RANDOM	5,34%	5,19%	4,85%
	FIXED	7,55%	5,14%	7,52%
	UNCOR.	4,90%	3,81%	4,95%

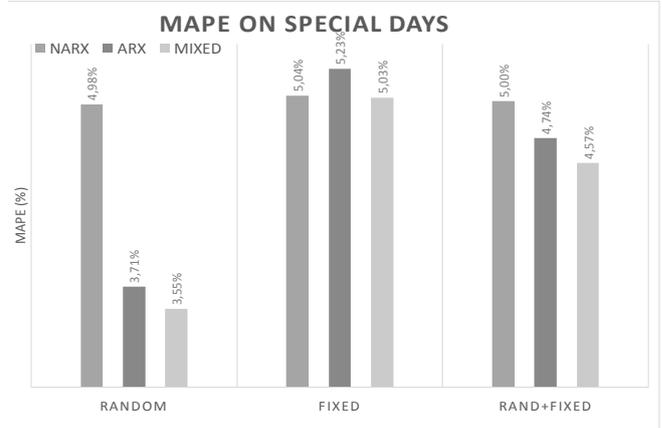


Fig 3. Forecasting Error on Special Days grouped by forecasting model and type of variable category. Mixed model obtains the most accurate forecast on special days.

#### B. Aggregated results

The results of aggregating the forecast of all three regions to obtain a general forecast are shown in Table 6. These type of accumulated data is also useful at the TSO's headquarters. Another interesting conclusion can be obtained analyzing these data: withal each of the regional forecasts made by the mixed model is more accurate than that of the autoregressive one. Conversely, the aggregate of both forecast do not show the same improvement. It is due to the mixed model is more precise because it learns from the behavior of other regions, whilst the autoregressive considers only regional data. The mixed model takes advantage of this possibility and shows a more accurate forecast when we compare regional forecasts. Nonetheless, the inaccuracies of the autoregressive model are averaged out and for this reason it obtains a similar result to the mixed model when we focus on the aggregate result.

TABLE VI. AGGREGATED FORECAST ERROR.

AGGREGATE	# DAYS	ARX	NARX	MIXED
RANDOM	25	2,32%	3,68%	2,33%
FIXED	54	3,33%	3,49%	3,34%
UNCORR.	286	2,31%	2,20%	2,28%
ALL	365	2,45%	2,49%	2,46%

#### C. Combination of forecasts

Assessing its contribution to the whole system it has been analyzed the new forecast. The TSO's forecasting system includes two forecasts that are combined to obtain a final output, as it was previously stated. The result of the three possible optimal combination of each couple of forecasts

when pooling all forecasts together is showed in Table 7. It can be concluded from these data, that all models are improved when joined with a different model, even if the other model is less accurate. The combination of the autoregressive and mixed models contributes very little improvement even when both models are highly correlated. If the mixed model is adjudged a heavier weight than the autoregressive model when teamed up with the NARX model it will obtain a lower error. Then, the mixed model should take over from the autoregressive model in the system.

TABLE VII  
WEIGHTS OF COMBINED FORECASTS AND ERROR.

	ARX (%)	NARX (%)	MIXED (%)	MAPE ON FIXED & RANDOM DAYS
COMB 1	62	38	0	4,32%
COMB 2	0	30	70	4,22%
COMB 3	12	0	88	4,51%

#### IV. CONCLUSION

This research presents an introduction of mixed models to STLF systems. Specially, to improve the individual forecast of similar regions that are affected similarly by the same phenomena like holidays, day-light savings time or other socioeconomic factors is used the ability of mixed effects models to manage multi-level data

The analysis presents an application, of an autoregressive model. The starting point to develop the mixed effect model was the one currently in used by the TSO. For the forecasts it was used data from several years to train the model. One full year was forecasted to provide a robust results database.

When results were compared to two models currently working the system provided a 4% average error reduction in comparison to the original autoregressive model. The same error reduction was obtained on special days on the three regions analyzed. Moreover, the combination of the now three available forecasts is analyzed and the results show that the new mixed model proposed provides a better alternative than using the two already available model. This research presents the best option that is to combine the NARX model with the mixed model, this mix will provide a 4.22% of MAPE error that is lower than the previous models.

In conclusion, the use of mixed models in STLF of similar regions is recommended over non-hierarchical models. By using a mix of models let on to use information from similar regions to improve accuracy of each of one. This is an important advantage when using special days, and when it is scarce the available data unit from which to learn the behavior.

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# Micromechanical Modeling of Fiber-Matrix Debonding in Unidirectional Composites

M. Palizvan, M. T. Abadi, M. H. Sadr

**Abstract**—Due to variations in damage mechanisms in the microscale, the behavior of fiber-reinforced composites is nonlinear and difficult to model. To make use of computational advantages, homogenization method is applied to the micro-scale model in order to minimize the cost at the expense of detail of local microscale phenomena. In this paper, the effective stiffness is calculated using the homogenization of nonlinear behavior of a composite representative volume element (RVE) containing fiber-matrix debonding. The damage modes for the RVE are considered by using cohesive elements and contacts for the cohesive behavior of the interface between fiber and matrix. To predict more realistic responses of composite materials, different random distributions of fibers are proposed besides square and hexagonal arrays. It was shown that in some cases, there is quite different damage behavior in different fiber distributions. A comprehensive comparison has been made between different graphs.

**Keywords**—Homogenization, cohesive zone model, fiber-matrix debonding, RVE.

## I. INTRODUCTION

SINCE fiber-reinforced composite materials have strong mechanical performance (high stiffness and strength to the weight, higher fatigue life, corrosion resistance, and a reasonable production cost), they have been applied in a wide range of structural applications, especially in the aerospace industry. The desired performance of a fibrous composite material could be achieved by choosing different constituents, different volume fractions, and various matrix-fiber arrangements. In order to use any sort of composite materials, it is certainly essential to understand their mechanical properties at different scales. However, the mechanical response of composite materials may be affected by several damage mechanisms in which the fiber matrix debonding and matrix cracking are of the primary damage modes. Although the initiation and propagation of these damage modes will not cause the collapse of the structure directly; however, they instantly will decrease the strength of the damaged layer a bit.

Note that the lack of an integrated computational framework for predicting the mechanical response of fiber-reinforced composite materials could lead to a huge number of experimental tests for the reliable design of structural components. An alternative approach is to employ a RVE [1] to synthesize realistic models of the fiber-reinforced

composite microstructure. RVE is a statistical representation of typical material properties. RVE is widely used in nowadays mechanics, and many authors were using the concept of RVE for theoretical, numerical, and experimental purposes [1]-[9].

Many researchers have studied the impacts of the probable damage modes in the response of composite materials with special consideration on fiber-matrix debonding based on micromechanics of RVEs. Mishnaevsky and Brondsted [2] have used a cohesive damage modeling approach to investigate the mechanical behavior and damage evolution of glass fiber-reinforced composites. The authors have developed a code for automatic generation of micromechanical unit cells of composites with damageable elements. The statistical variability of fiber strength, fiber-matrix interface debonding, and other features have been embedded into the code. Numerical experiments have been conducted using the generated unit cell models to investigate different fiber packing geometries.

A Cohesive Zone Model (CZM) was proposed in [3] to describe the fracture of adhesively bonded polymer-matrix composites. More recently, an inverse procedure to identify the mode I cohesive parameters of bonded interfaces is proposed in [4]. It bears emphasis that some of the fracture parameters can be obtained using purely experimental based approaches or J-integral related methods.

Melro et al. [5], [6] presented the application of a constitutive damage model for an epoxy matrix on micromechanical analyses of polymer composite materials. Different RVEs with periodic boundary were generated with a random distribution of fibers. The focus was given to the influence of the interface between fiber and matrix, as well as to the importance of the epoxy matrix, on the strength properties of the composite, damage initiation and propagation under different loading conditions. The impact of the interface properties (interface strength and toughness) on the tensile deformation was studied in a model composite made of a random distribution of stiff spherical particles embedded in a ductile matrix by Segurado and Llorca [7]. The composite behavior was simulated through the finite element analysis of an RVE of the composite microstructure, and interface decohesion was included by means of interface elements whose response was governed by a cohesive crack model. The ability to use the changes in elastic stiffness or in volumetric strain to monitor damage during deformation was determined and simple models of continuum damage mechanics based on these parameters failed to predict the composite flow stress in the presence of interface decohesion.

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## II. MODELLING THE COHESIVE ZONE

Fiber-matrix debonding is one of the most common types of damage in micromechanical scale in laminated fiber reinforced composites due to their relatively weak interlaminar strengths. Fiber matrix debonding may significantly affect the composite stiffness and strength. It may arise in such structures under various circumstances, but most of the time when subject to transverse loadings.

The CZM approach has emerged as a powerful analytical tool for nonlinear fracture processes. CZMs have particularly been used to analyze composite debonding problems. However, in many studies, they had the assumption of the existence of initial defects or cracks and could not be applied directly without initial debonding. But, this limitation becomes very challenging or even impossible when a random distribution of fibers is utilized for an RVE with hundreds of fibers. In many applications, stress-based methods have to be used to predict the initiation of debonding, following which fracture mechanics can be applied to describe the propagation of existing debonding, see for example [6], [8], [9].

A micromechanical model for composite microstructures undergoing fiber-matrix interfacial debonding has been developed in Swaminathan et al. study [10]. In this model, the fiber-matrix interface behavior is modeled by a nonlinear CZM with bilinear traction-displacement relations in both normal and tangential directions. Bilinear CZMs show an acceptable agreement with experiments for composite materials described in [11], [12]. The interface is modeled by a set of cohesive springs that are tied to the fiber and the matrix at both sides. By increasing displacement, the traction across the interface increases to a maximum value, then decreases with further displacement increase, and at the end, vanishes indicating failure of the spring.

## III. GENERATION OF RANDOM RVEs

The introduction of randomness to the fiber positions in the microstructure is desirable for a variety of reasons. It results in a more realistic microstructure. Randomness leads to fibers in very close proximity to one another, which gives rise to high-stress concentrations. These concentrations will strongly influence extreme-based mechanisms such as failure and plasticity. The introduction of randomness can also be useful for the characterization of uncertainty in composite properties. The use of random microstructures to predict the behavior of composites is not new.

Firstly, in order to analyze the mechanical properties of composites, considering their microstructure details, an appropriate RVE model of composites should be defined. In this section, the procedure is illustrated for the automatic generation of RVE models with a random distribution of fibers. A micrograph of an actual lamina illustrates that physical lamina does not exhibit a uniform distribution of fibers but rather have some random distribution. As a result, this work aims to model the lamina microstructure more accurately by introducing randomness into the arrangement of fibers. These models could be used for long fiber reinforced

composite micro-mechanical analysis. The program code is developed in MATLAB language. Then, one can use the files to generate RVE and execute subsequent numerical analysis conveniently.

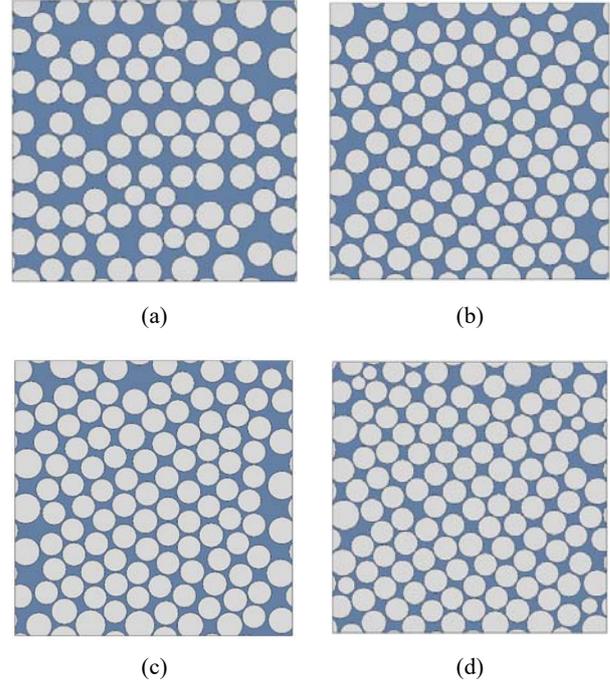


Fig. 1 Random fiber distribution in RVE for different fiber volume fraction, (a) 60%, (b) 65%, (c) 70%, (d) 75%

## IV. MICROMECHANICAL PROPERTIES EVALUATION

Various finite element analyses with different fiber volume fraction RVEs are generated. For the elastic material behavior section, several papers are validated with different material behavior, RVE size, fiber size, etc.

### A. Finite Element Analysis

Finite element (FE) analysis was carried out using ABAQUS [13] under plane strain condition. In the ABAQUS model, both the matrix and the fibers were meshed using free meshing technique with quad-dominated element shapes. The two-dimensional 4-node bilinear plane strain quadrilateral elements (CPE4) were chosen to mesh the fiber and the matrix. There was also a relatively small amount of 3-node linear plane strain triangle elements (CPE3) due to the free meshing technique used. Since each model has about 500 fibers, it is difficult and time-consuming to generate each RVE manually. Therefore, python scripts have been written to generate and distribute fibers in the FE models of the RVEs in ABAQUS [13].

### B. Periodic Boundary Conditions

The importance of periodic boundary conditions in the world of micromechanical analysis has been demonstrated by several authors [14]-[16]. The present subsection is devoted to the derivation of the equations to be applied to the RVE's mesh in order to implement this type of boundary conditions.

Periodic boundary conditions force such a deformation on the volume element that the displacement of one of the nodes belonging to one edge must be related to the displacement of the corresponding node in the opposite edge. Fig. 2 exemplifies the final result.

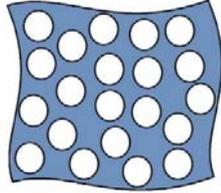


Fig. 2 Periodic boundary conditions

Barbero [16] provides a set of equations that allow the application of periodic boundary conditions in a RVE. All equations must be applied to opposite nodes on the faces, edges, and vertices of the RVE. Not only the degrees of freedom of these nodes are variables in these equations but also the far-field applied strains. Depending on which position the nodes are – edges or vertices – a different set of equations must be applied to its degrees of freedom. These equations can be incorporated in a FE analysis by using linear multi-point constraints.

#### V. ANALYSIS AND RESULTS

The current section is dedicated to the analysis of debonding damage behavior of long fiber composite materials at micro-scale. To study the trends thoroughly, different RVEs configurations implemented. Two types of regular fiber distribution in the matrix are investigated, the square and hexagonal array fiber distributions; the third form is a random distribution. The results are presented for 20, 40, and 60 percent of fiber volume fractions.

Throughout the studies, a square of 100 by 100 micrometers and a fiber radius of 5 micrometers are assumed and material properties are taken from Legard et al. [17]. Material models are assumed to be linear elastic for matrix and fibers, and their interaction is modeled using cohesive elements. Each case is studied by mean of Von-Mises stress distribution contour investigations as well as deformation description and stress-strain and damage propagation behavior. The analyses are continued by debonding study as mean of damage indicator and its effect on Poisson’s ratio of RVEs.

##### A. Square Array Distribution

The RVEs with the square array distribution of the fibers are analysed under uniaxial tension, the Von-Mises stress contour for RVEs with 20%, 40% and 60% fiber volume fractions are shown in Fig. 3. The deformation of RVEs after loading ( $\epsilon_{xx} = 0.02$ ) and the distribution of interfaces that included fiber-matrix debonding are different in various fiber volume fractions.

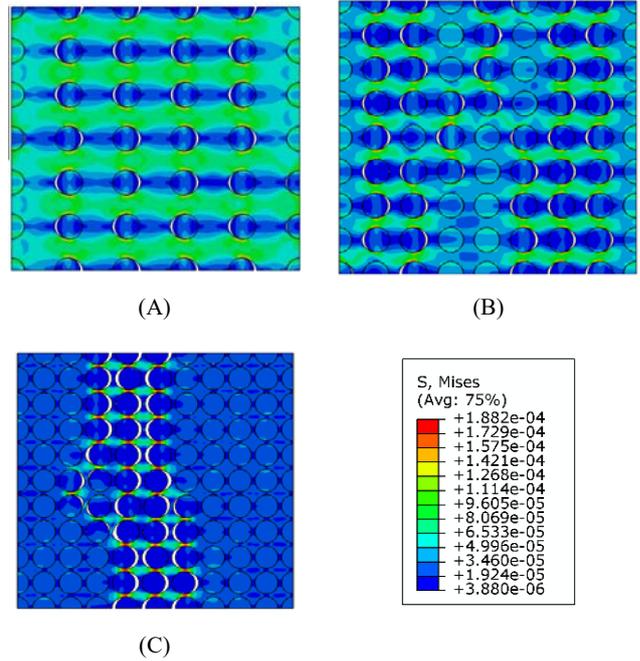


Fig. 3 Von-Mises stress contour for RVEs with 20%, 40%, and 60% fiber volume fractions and square array fiber distributions (Stress in  $Pa \times 10^{-12}$ )

In the RVE with 20% fiber volume fraction, Fig. 3 (A), almost all the fibers experienced the fiber-matrix debonding. In the other words, the damage has spread all over the RVE. However, in RVE with 40% fiber volume fraction and square array fiber distribution, Fig. 3 (B), the only fibers that are in the two left and right strips are debonded and the fibers in the middle of the RVE have remained perfectly without damage. This phenomenon is observed in RVE with 60% fiber volume fraction in a different scheme, see Fig. 3 (A). Only a narrow strip of fibers in the middle the RVE contains debonding in their interfaces, and the rest of the fibers remain completely undamaged.

By increasing the fiber volume fraction and by keeping the radius constant, the number of fibers within the RVE increases obviously. And when the loading is done, the fibers inside the RVE are debonded and with every fiber-matrix debonding, specific amount of energy is dissipated. In the low fiber volume fraction RVEs (in this case 20%), all fibers must be debonded to provide the dissipated energy. However, with increasing fiber volume fraction, a lower percentage of fibers is needed to provide it. It should be noted that due to the different amount of damage developed in different RVEs, after loading ( $\epsilon_{xx} = 0.02$ ), the amount of dissipated energy is varied.

This phenomenon can be described in another way. The RVEs with low fiber volume fraction has fewer fibers. So, the distances between the fibers are more than the distances between the fibers with higher fiber volume fraction. In this case, there is a more uniform distribution of stress in the RVE even when some debonding occurred. This uniform distribution of stress is caused by the elastic properties of the

matrix and the adequate distance of the fibers from each other. However, in the RVE with more fiber volume fraction (40% and 60%), the fibers must place with less distance so there is a narrower matrix band between them. In another word, in the same area, more fibers should be placed. The damage will have a greater impact on the distribution of the stress of the neighboring fibers when the fibers are close to each other. For this reason, when the first fiber matrix debonding occurred in the fibers' interaction, the following stress concentration will cause the next debonding in the neighboring fibers. And that's why in the high fiber volume fraction RVEs, the damage is clustered and occurs only in certain sections in the RVE.

The stress-strain relations for RVEs with square array fiber distribution are shown in Fig. 4 (A), it can be understood that damage in lower fiber volume fraction is occurred in a larger strain in compare by higher ones. As it can be seen in Fig. 4 (A), for RVE with square array fiber distribution and 20%, 40% and 60% fiber volume fractions, damage initiates in strain  $\epsilon = 0.0087, 0.0065$  and  $0.0046$ , respectively.

Damage initiates earlier in RVE with 60% fiber volume fraction because the fibers are very close to each other which is lead to more stress concentrations. On the other hand, according to Fig. 4 (A), besides the earlier damage initiation, the stiffness loss is more and about 15 MPa. The remarkable point is that although the RVE with 20% fiber fraction has a lower stiffness, its strength is more than the other RVEs. This can be explained by the fact that due to the earlier debondings initiate in the RVE with 60% volume fraction and the subsequent debondings caused by stress concentrations, the RVE with more fiber volume fractions show lower stress strength.

At all stages of loading from the first debonding, the amount of damage for RVE with 60% volume fraction is higher than the others and ultimately reaches  $D=0.73$  in strain  $\epsilon = 0.02$ . This is while for the other two RVEs, damage reaches  $D=0.65$  and  $0.42$  for 40% and 20% volume fractions, respectively.

The variation of the Poisson's ratio to the initial value is shown in Fig. 4 (B). Since damage is zero at the beginning of loading, the effective material properties have still remained in the elastic regime so in the absence of damage, the Poisson's ratio stayed unchanged. By the first damage initiation, the Poisson's ratio starts to decrease uniformly and with different slopes in all three RVEs. Since the most damage is made in RVE with 60% fiber volume fraction, the Poisson's ratio drop is larger than the other RVEs.

**B. Hexagonal Array Distribution**

To have a better perspective of the behavior of RVE with regular fiber arrangement containing fiber-matrix debonding, three RVEs with 20%, 40%, and 60% fiber volume fraction considered with hexagonal array fiber distributions in this section. The Von-Mises stress contours at strain  $\epsilon_{xx} = 0.02$  for these RVEs are shown in Fig. 5.

Just like the previous section, square array fiber distribution, the debondings are spread all over the RVE with 20% fiber volume fraction. This means that the debonding is

almost happened for all the fibers, see Fig. 5 (A).

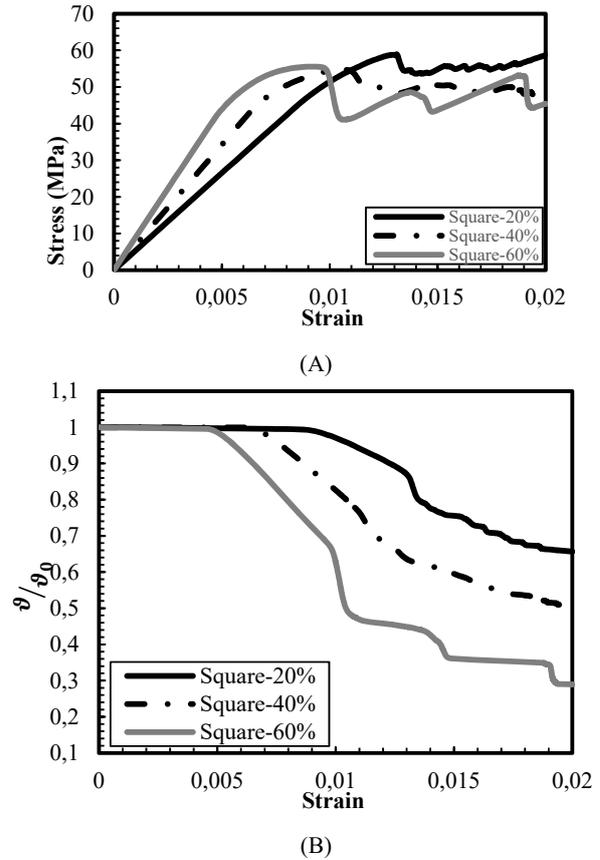


Fig. 4 (A) stress-strain relation and (B) Poisson's ratio variation-strain relation obtained from modeling three RVEs with square array distributions with 20%, 40%, and 60% fiber volume fractions under uniaxial loading

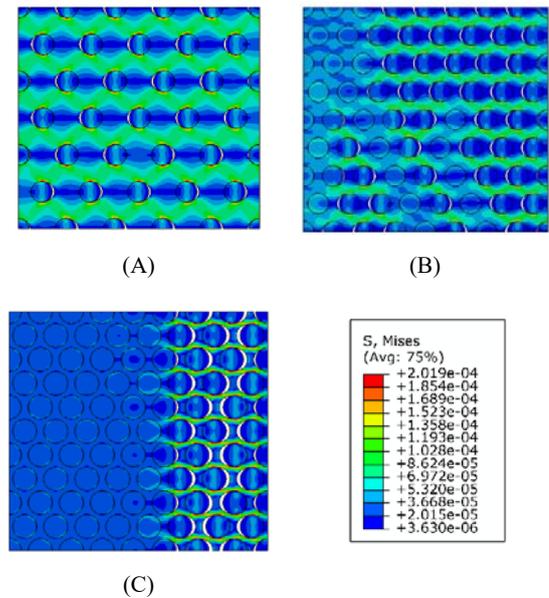
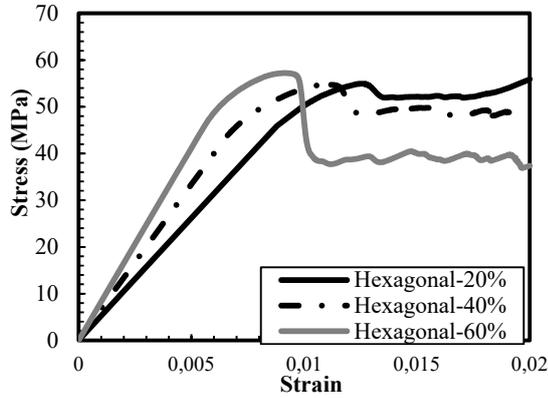
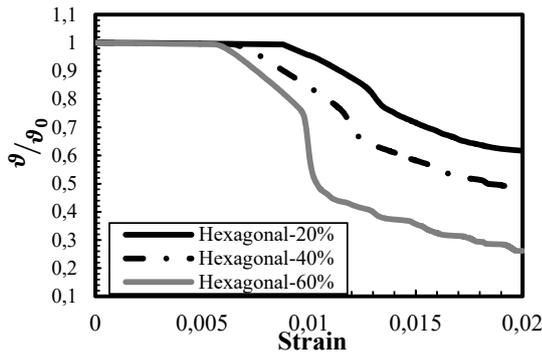


Fig. 5 Von-Mises stress contour for RVEs with 20%, 40% and 60% fiber volume fractions and hexagonal array fiber distributions (Stress in  $Pa \times 10^{-12}$ )

Once again, the fibers debonded in two groups in two side of the RVE for 40% volume fraction shown in Fig. 5 (B). This two groups of fibers contain fiber-matrix debonding in their interactions are asymmetric in hexagonal array distribution. However, we can see almost a symmetric scheme of debonding in 40% fiber volume fraction with square array distribution.



(A)



(B)

Fig. 6 (A) stress-strain relation and (B) Poisson's ratio variation-strain relation obtained from modeling three RVEs with hexagonal array distributions for 20%, 40% and 60% fiber volume fractions under uniaxial loading

Although as we expected, the debonding for 60% fiber volume fraction happens in a narrow strip of the fibers unlike the square array fiber distribution, the strip of debonded fibers is located at the vicinity of loading edge.

Stress-strain curves are illustrated in Fig. 6 (A) for three different fiber volume fractions in RVEs with hexagonal fiber distribution. The RVE with 60% fiber volume fraction experiences fiber-matrix debonding in strain  $\epsilon = 0.095$ , which results in a 20 MPa drop in its strength. Besides this early damage initiation, its ultimate strength is still more than two other fiber volume fractions. RVEs with 20% and 40% fiber volume fractions are decreased about 5 MPa in  $\epsilon = 0.0125$  and  $\epsilon = 0.0115$  in their stress curves, respectively.

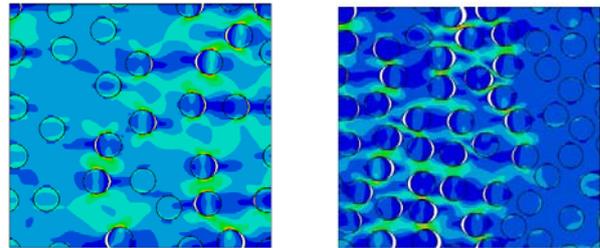
Fig. 6 (B) shows how the Poisson ratio changes. It can be concluded the with the increase of damage parameter, we have

degradation in Poisson's ratio. There is about 75, 50, and 35 percent reduction for the RVE with 60, 40, and 20 percent fiber volume fraction, respectively.

### C. Random Distribution

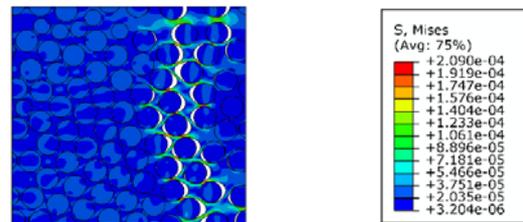
In the previous two sections, the damage behavior of RVEs with regular fiber distribution (square and hexagonal arrays) has been studied. While in fact the distributions of fibers in real composites are not regular, this can be an unrealistic assumption. In this section, RVEs with random fiber distribution have been modeled to have a more realistic damage initiation and propagation. Three random fiber distributions are assumed with 20%, 40%, and 60% fiber volume fraction, shown in Fig. 7.

Unlike the previous sections that almost all the fibers experienced the fiber matrix debonding in the 20% fiber volume fraction, in the random arrangement, a fewer number of fibers debonded (Fig. 7 (A)). It should be noted that the damage behavior of RVE has a strong dependency on the fibers locations in the random fiber distributions. And the debonding always develops in places where the most tension is applied to the cohesive interface. In this RVE, Fig. 7 (A), the location of the debonding could be predicted in advance, since the first debonding occurs at the place where the maximum tensile force is applied to the interface between the fiber and the matrix, or in the other words, the least load is tolerated at that cross-section of the matrix. This will occur at the cross-sectional stage where the matrix has the lowest width. It can be seen that seven fibers are located in the same vertical direction where the first debonding happened. There is the lowest width of the matrix in this vertical cross-section between the different sections in this RVE (Fig. 7 (A)).



(A)

(B)



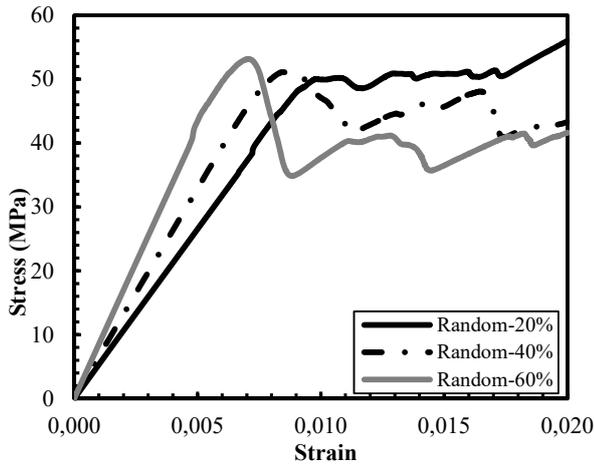
(C)

Fig. 7 Von-Mises stress contour for RVEs with 20%, 40%, and 60% fiber volume fractions and square array fiber distribution (Stress in  $Pa \times 10^{-12}$ )

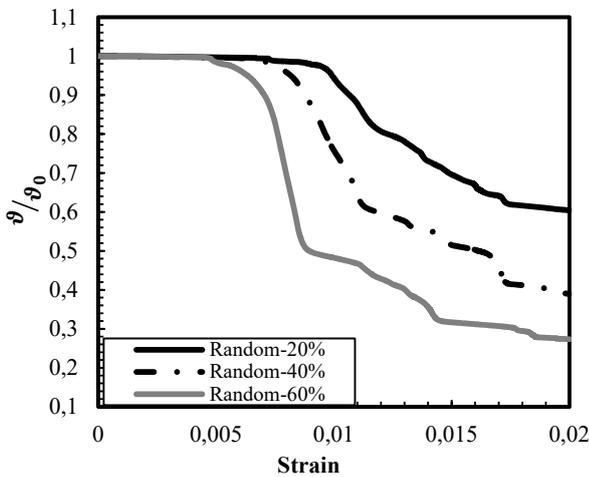
The deformation of the RVE with random fiber distribution

and 40% fiber volume fraction by  $\varepsilon = 0.02$  is shown in Fig. 7 (B). The debonding interfaces are located on the left side of the RVE, while in the two previous section (square and hexagonal distributions), in this fiber volume fraction, the debonding interfaces occurred on both sides of the RVEs.

Contrary to two RVEs with 20% and 40% fiber volume fractions that have a different distribution of damage regarding to the regular fiber distributions RVEs, in RVE with 60% fiber volume fraction (Fig. 7 (C)), the deformation and distribution pattern of the damage is very similar to distributions of damage in square and hexagonal fiber arrays. So, a narrow strip of fibers from the top to the bottom are debonded.



(A)



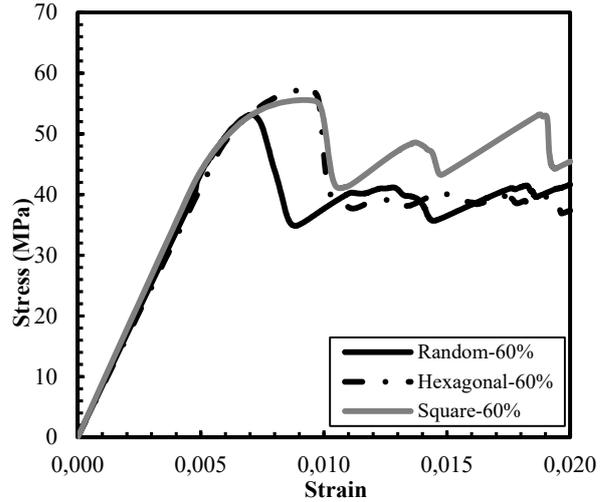
(B)

Fig. 8 (A) stress-strain relation and (B) Poisson's ratio variation-strain relation obtained from modeling three RVEs with random fiber distributions for 20%, 40% and 60% fiber volume fractions under uniaxial loading

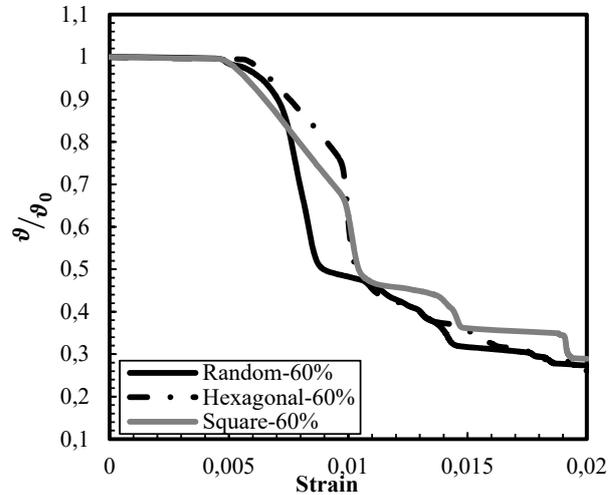
*D.RVEs with 60% Fiber Volume Fractions and Different Fiber Distributions*

As can be expected, by the change in fiber fraction, the RVEs behavior changes considerably. As fibers close in, damage initiation and propagation concentrate in the same

spots. In Fig. 9 (A), it is illustrated that randomly distributed RVE having 60 percent fiber fraction undergoes the decrease in stiffness sooner than ordered models for about 4 MPa less maximum stress; as observed in 20 and 40 percent fiber fraction RVEs. Introductory loss of stiffness in all three configurations is about 20 MPa. The observed decrease is gradual at hexagonal formation rather than a triple step reduction in the squared and random distribution of fibers. Finally, at 3 percent strain, bearing stress in squared order has the highest, while the hexagonal and fiber distribution model has the lowest stress-bearing capacity.



(A)



(B)

Fig. 9 (A) stress-strain relation and (B) Poisson's ratio variation-strain relation obtained from modeling three RVEs with 60% random fiber volume fraction for square array, hexagonal array and random distributions under uniaxial loading

VI. CONCLUSION

A micromechanical study to predict the mechanism of debonding of a fibrous composite material under transverse tension to the fibers has been carried out. Several RVEs with

regular (square and hexagonal arrays) and random fiber distributions have been studied by means of the FE method, considering an interface crack between the fiber and the matrix.

Through the use of RVEs, we demonstrate the influence of interphases and interfacial debonding on the global response of fibrous reinforced composites. We capture the interfacial debonding behavior of the fibers, at large strains, using cohesive elements. It has been shown that interphases significantly alter the macroscopic constitutive response of these composite materials. This study indicates that the proposed computational framework is able to provide an explanation for the varied macroscopic response of fiber reinforced composite. Because of the challenges associated with experimentally obtaining the necessary measurements of material properties, a computational framework, such as the one presented in this paper. In summary, this paper has been able to clearly demonstrate the significance of interphases and interfacial debonding on the macroscopic constitutive response of fibrous reinforced composites.

Ultimately, the goal would be to use this investigation as an introduction of part two in which both fiber-matrix debonding at fiber interface and matrix cracks are considered at the same time.

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# A Numerical Method to Evaluate the Elastoplastic Material Properties of Fiber Reinforced Composite

M. Palizvan, M. H. Sadr, M. T. Abadi

**Abstract**—The representative volume element (RVE) plays a central role in the mechanics of random heterogeneous materials with a view to predicting their effective properties. In this paper, a computational homogenization methodology, developed to determine effective linear elastic properties of composite materials, is extended to predict the effective nonlinear elastoplastic response of long fiber reinforced composite. Finite element simulations of volumes of different sizes and fiber volume fractions are performed for calculation of the overall response RVE. The dependencies of the overall stress-strain curves on the number of fibers inside the RVE are studied in the 2D cases. Volume averaged stress-strain responses are generated from RVEs and compared with the finite element calculations available in the literature at moderate and high fiber volume fractions. For these materials, the existence of an RVE is demonstrated for the sizes of RVE corresponding to 10–100 times the diameter of the fibers. In addition, the response of small size RVE is found anisotropic, whereas the average of all large ones leads to recover the isotropic material properties.

**Keywords**—Homogenization, periodic boundary condition, elastoplastic properties, RVE.

## I. INTRODUCTION

THE prediction of the effective elastoplastic response of fibrous composite materials consisting of linear elastic fibers and elastoplastic matrix, such as epoxy matrix composites reinforced with glass fibers, is an important and active research topic (see, e.g., [1]-[3]). Progress in computational techniques of the last decade has provided powerful tools for the solution of this problem. Commercial computational packages like ANSYS and ABAQUS based on the finite element method (FEM) allow one to solve the homogenization problem on the basis of calculation of the detailed stress and strain fields in a RVE of a composite that contains tens of fibers of various shapes and properties. The result of prediction is often presented in the form of stress-strain relation under some simple loading, say, simple tension or pure shear.

Existing methods for predicting the elastoplastic response of composite materials include the secant homogenization method [4], incremental homogenization method based on the Mori–Tanaka model [5], the direct approach using RVEs [2], and periodic unit cell method [6]. The secant method is limited to monotonic and proportional loading. The incremental

homogenization method has no such limitation and can be applied to load reversal or cyclic load. However, in its original form, the incremental approach over-predicts elastoplastic stress-strain response and the remedy is to use only the isotropic part of the anisotropic elastoplastic tangent stiffness tensor [5]. However, the use of only the isotropic part of the tangent stiffness tensor, while resulting in much-improved prediction, lacks either theoretical or physical basis. In addition, fitting parameters may be needed in formulating the isotropic part of the tangent stiffness tensor [7]. It is well known that for a particulate composite with its matrix material characterized by the von Mises yield condition (the theory of J2 plasticity), reinforced with homogeneous, isotropic and linearly elastic particles, the composite as a whole may yield under hydrostatic stress even though the matrix does not [8]-[10].

The direct approach using RVEs gives a rigorous prediction of the effective composite elastoplastic response, but is computationally expensive, particularly given the nonlinear nature of plastic deformation. The unit cell method applies to composites with periodic microstructures. It cannot be rigorously applied to real composites which in general are not periodic. Because of its simplicity, the unit cell method is nonetheless often used to approximate the elastoplastic behavior of real composites [11], [12]. In addition to the aforementioned methods, Sun and Ju [13] applied the ensemble averaging approach to the prediction of the effective elastoplastic response of particulate composites.

The primary methods for studying the effective material properties of the RVE include approaches based on analytical homogenization schemes, mainly restricted to linear cases. These techniques (e.g., [14]-[16]) have been used to consider different shapes of inclusions and have been useful in some situations to determine the effective material properties of the RVE with respect to the inclusions' characteristics. On the other hand, some approaches based on numerical methods, such as the FEM (e.g., [17]-[20]), use computations on a unit cell and allow determining the size of the RVE via statistical analyses relying on numerical computations. These techniques have been mainly applied in the linear case, and a few recent studies involve nonlinear heterogeneous materials. For linear composites, determining the size of the RVE can be performed by analyzing the statistical convergence of effective material parameters with respect to the size of the unit cell. Kanit et al. [21] studied the linear thermal and elastic properties of random 3D polycrystalline microstructures. Ranganathan and Ostoja-Starzewski [22] investigated random polycrystal microstructures made up of cubic single crystals. Other examples in elasticity can be found in [23]-[27]. In [28], new

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criteria to determine the size of RVE with random elastic matrix have been proposed as well as estimates for RVE sizes. In [29], a stochastic homogenization theory has been introduced for random anisotropic elastic composites that cannot be described in terms of their constituents and for which the standard methods cannot be applied, like cortical bones or biological membranes. In [30], a method using the concept of periodization of random media was used to estimate the effective properties of random composites using small volumes.

For nonlinear composites, most of the proposed methodologies are based on analyzing the convergence of the effective response (e.g., the effective stress), computed numerically at one point of the loading curve with respect to the size [31]-[33]. More recent studies analyze the convergence of identified parameters related to an empirical macroscopic model with respect to the unit cell size [34], [35].

Although reliable micromechanics models for linear elastic composites have been available for a long time, developing models approaches for nonlinear composites remains highly challenging. The aim of the present work is to develop a numerical algorithm which is able to simulate, with reasonable accuracy, computer time, and memory the elastoplastic behavior of matrix composite materials. The numerical estimates of the stress-strain response and their scatter obtained on volumes of fixed size but containing different realizations of a given volume of the microstructure are investigated.

The present paper is organized as follows. In Section II, a plasticity model is presented to show how we simulate the mechanical behavior of the matrix, based on available experimental evidence, and also, periodic boundary conditions and numerical homogenization methods are illustrated. The analysis models, computational implementation, and results are presented and discussed in Section III. Some concluding remarks are given in Section IV.

## II. PLASTICITY THEORY

The current section provides an overview of the theoretical aspects of plasticity. The books [36]-[39] provide a more detailed and broader perspective on the general theory of plasticity as well as its phenomenological aspects. In this thesis, only small deformations will be considered. This assumption is justified by the presence of cracking for small deformations. Considering only small-strains will also allow simplifying the model's definition and implementation.

Fig. 1 shows the mathematical idealization of a typical stress-strain curve of a uniaxial tensile test on an elastoplastic material.

The segment A – B represents the elastic domain of the material behavior. The initial Young's modulus is given by the slope of this segment and remains constant in the elastic domain. Under elastic behavior, it is considered that there are no permanent deformations, and all strains can be recovered upon unloading. This elastic behavior ends when the yield stress  $\sigma_0$  is met (point B). From this moment on, the material begins suffering permanent plastic strains. The material can

also suffer hardening, i.e. the yield stress increases as the plastic strains accumulate. This can be seen in Fig. 1 in segment B – F. At point C, for example, the accumulated plastic strain is given by  $\varepsilon^p$  and the increase of the yield stress from  $\sigma_0$  to  $\sigma_0^1$ . This increase continues until the material reaches the ultimate strength (point F) and fails.

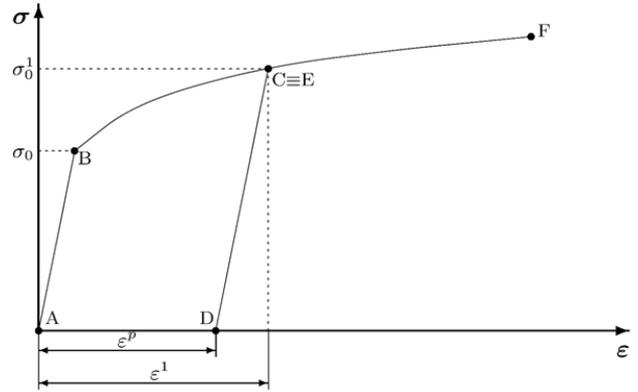


Fig. 1 Mathematical model of uniaxial tensile test

If the material is unloaded from point C, it will recover some of the accumulated strain,  $\varepsilon^1$ . In other words, at any given point of the loading curve under the plastic domain, the strain tensor can be decomposed in two components: one elastic (and thus recoverable) component, and one plastic (or permanent) component. For the uniaxial example in Fig. 1, the recovered elastic strain after unloading (segment C – D) is given by:

$$\varepsilon^e = \varepsilon^1 - \varepsilon^p \quad (1)$$

In the most general case, the strain tensor is decomposed according to

$$\varepsilon = \varepsilon^e + \varepsilon^p \quad (2)$$

where  $\varepsilon^e$  is the elastic strain tensor and  $\varepsilon^p$  is the plastic strain tensor.

In a uniaxial test, the yield stress is nothing but a scalar (Fig. 1). However, in a general three-dimensional case, the elastic domain is bounded by a yield surface instead. This surface is defined in the most general case by:

$$\Phi(\sigma, q) = 0 \quad (3)$$

where  $q$  represents a set of variables affected by the hardening (or softening) process. This scalar function delimits the region in the stress space where any point inside the surface,  $\Phi < 0$ , is in the elastic domain and any point on the surface,  $\Phi = 0$ , corresponds to plastic yielding.

As the hardening variables increase in value (or decrease), so will the yield surface expand (or shrink). This effect is known as isotropic hardening (or softening). In the most general case, the surface can even change its shape or translate in the stress space (kinematic hardening or softening).

A. Computational Implementation

In this section, in order to evaluate the effect of the variability of the RVE on the mechanical properties of composites, stiffness analyses are performed. As done for other algorithms [40], [41], the present algorithm is used to generate the RVEs of the transverse section of a composite lamina. The effective elastoplastic material from the properties of their constituents is then evaluated by finite element models.

Various finite element analysis with different fiber volume fraction RVEs is generated. For the elastic material behavior section, several papers are validated with different material behavior, RVE size, Fiber size, etc.

The overall integration algorithm as it was implemented in a UMAT subroutine of commercial finite element software ABAQUS [42] is presented in the flowchart of Fig. 2. It follows a typical implicit elastic predictor/return mapping procedure used by, for example, Souza-Neto [39]. It begins by computing an elastic trial stress state and up-to-date hardening variables. If the trial stress state is still inside the paraboloidal yield surface, then the increment is considered to be fully elastic; otherwise, the algorithm for the return mapping is executed. Upon convergence of the plastic multiplier, all state variables, stress tensor and plastic strain tensor are updated accordingly.

Finite element (FE) analysis was carried out using ABAQUS [42] under plane strain condition. In the ABAQUS model, both the matrix and the fibers were meshed using structured meshing technique with quad-dominated element shapes. The two-dimensional 4-node bilinear plane strain quadrilateral elements (CPE4) were chosen to mesh the fiber and the matrix. There were also a relatively small amount of 3-node linear plane strain triangle elements (CPE3) due to meshing technique used. Since each model has so many fibers, it is difficult and time-consuming to generate each RVE manually. Therefore, Python scripts have been written to generate and distribute fibers in the FE models of the RVEs in ABAQUS [42].

III. ANALYSIS AND RESULTS

In this paper, the material that has been chosen to study is consisting of E-glass fibers and epoxy resin as a matrix. The properties have been reported and used by Fiedler et al. [43]. Both the matrix and the fiber are treated as isotropic for the 2D model. The elastic properties of the fiber and the matrix are shown in Table I, while Table II summarizes the plastic properties of epoxy measured from tensile tests by Fiedler et al. [43].

TABLE I  
MATERIAL CONSTANTS FOR CONSTITUENTS OF THE COMPOSITE

Constituent	Young's modulus	Poisson's ratio
Fiber	70 GPa	0.2
matrix	3.35 GPa	0.35

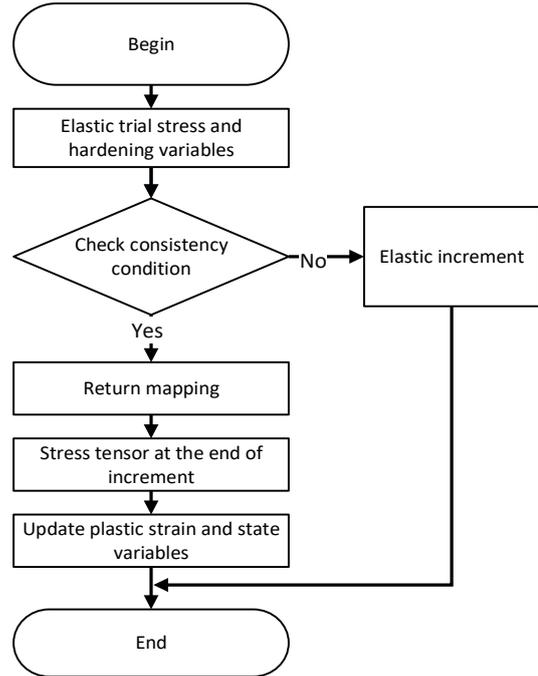


Fig. 2 Flowchart of implicit elastic predictor/return mapping algorithm

TABLE II  
THE PLASTIC PROPERTIES OF EPOXY

$\epsilon_p^e(\%)$	$\sigma_T(MPa)$	$\epsilon_p^e(\%)$	$\sigma_T(MPa)$
0.00	29.0	0.85	81.5
0.03	37.0	1.02	84.5
0.06	45.0	1.20	87.0
0.13	52.0	1.41	89.0
0.19	58.0	1.62	91.0
0.30	65.0	1.81	92.5
0.39	70.0	2.04	93.5
0.53	74.0	2.27	94.5
0.69	78.0	2.50	95.0

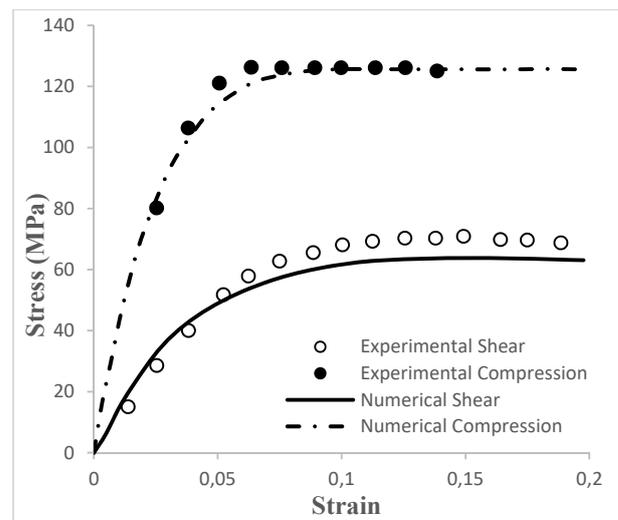


Fig. 3 Comparison of experimental data [43] with numerical results from matrix mesh

In order to verify the developed method with other solutions, several RVEs with different fiber distributions were generated. The elastoplastic constitutive model was implemented in a user subroutine UMAT in ABAQUS.

Two different unidirectional analyses were performed on a simple two-dimensional matrix mesh – tension and shear. In Fig. 3, the results are compared with the experimental data from Fiedler et al. [43]. Considering that tension result is in good agreement by default with the experimental data, since it is based on these values that the plastic behavior of the matrix is modeled. The numerical results for shear agree very well

with the available experimental data, despite some under-prediction of the maximum stress.

For the next step, we tried to calculate the effective properties by using the homogenization method. The aim of this section is to calculate a relation between stress and plastic strain which can be used for introducing the new material in ABAQUS software for further analyses. Two methods for deriving these relations are used. In the first method, true stress and strain are obtained in terms of engineering stress and strain by (4) and (5).

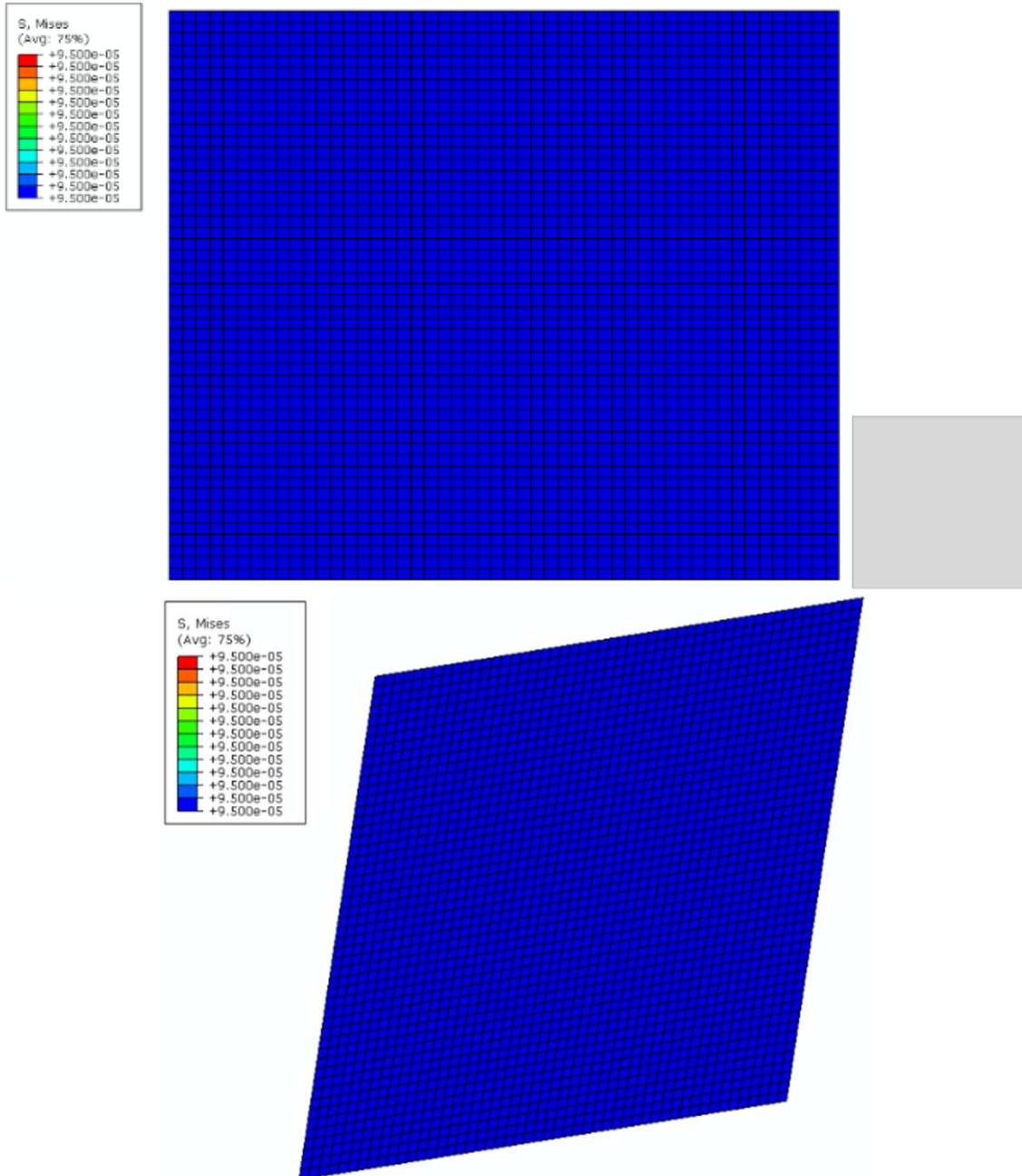


Fig. 4 RVE used to verify the developed method with the experimental data from Fiedler et al. [43]

It is important to note that (4) should only be used until the onset of necking. Beyond maximum load, the true stress

should be determined from actual measurements of load and cross-sectional area.

$$+\sigma_{tru}=\sigma_{nom}(1+\varepsilon_{nom}) \quad (4)$$

The true strain  $\varepsilon_{tru}$  may be determined from the engineering or conventional strain  $\varepsilon_{nom}$  by

$$\varepsilon_{tru}=\ln(1+\varepsilon_{nom}) \quad (5)$$

Then, the elastic module is obtained from

$$E=\sigma_{tru}(1)/\varepsilon_{tru}(1) \quad (6)$$

And at last, plastic strain is calculated by

$$\varepsilon_{pl} = \varepsilon_{tru} - \frac{\sigma_{tru}}{E} \quad (7)$$

Or the second method, the overall plastic strain can be derived directly by the homogenization of plastic strain in each integration points all over the model. The average plastic strain in an RVE is defined by:

$$\bar{\varepsilon}_{pl} = \frac{1}{V} \int_V \varepsilon_{pl} dV \quad (8)$$

These two methods are performed, and the results are compared with the input plastic behavior introduced in Table II. The results are illustrated in Fig. 5. It is found that the new model formulation is capable of providing an accurate prediction of the effective elastoplastic response of fiber reinforced composites.

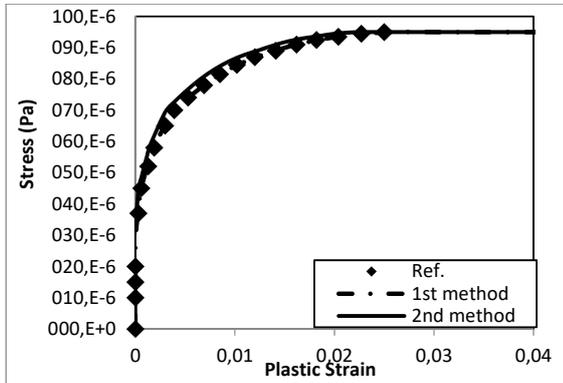


Fig. 5 Stress-plastic strain relationship for matrix

The next sections present a few examples of RVEs under different loading conditions and provide a better insight into the matrix material behavior defined by the present elastoplastic constitutive model.

Two loading conditions are presented: transverse tension and transverse shear. The elastic properties and plastic evolution data from Fiedler et al. [43] were used to model the epoxy mechanical behavior.

Since the goal of the current section is to provide an overview of the deduced elastoplastic constitutive model, different volume elements are chosen. Thus, the volume

element has more than  $10\times$  the fiber radius in the transverse direction. The minimum interval between any two neighboring fibers is set to  $0.1\times$  the fiber radius, and the fiber volume fraction is set to 45%.

Several different fiber distributions were generated, and the different loading conditions mentioned above were applied on each distribution independently. Each case will be analyzed in detail in the following.

#### A. RVE with 45% Fiber Volume Fraction

Fig. 6 shows a RVE with 45% fiber volume fraction and the results obtained by applying transverse tension and shear load to it. Figs. 6 (B) and 8 (E) show the spatial distribution of the equivalent von-Mises for the generated fiber spatial distribution in transverse tension and shear loadings, respectively. Moreover, Figs. 6 (C) and 8 (F) illustrate the equivalent plastic strain for transverse tension and shear loadings, respectively. It can be seen that the regions where the equivalent plastic strain is greater are located between those neighboring fibers aligned with the load direction (horizontal, in this case).

After homogenization is done, the effective material properties are calculated and used for analyzing the RVE with the homogenized material characteristic.

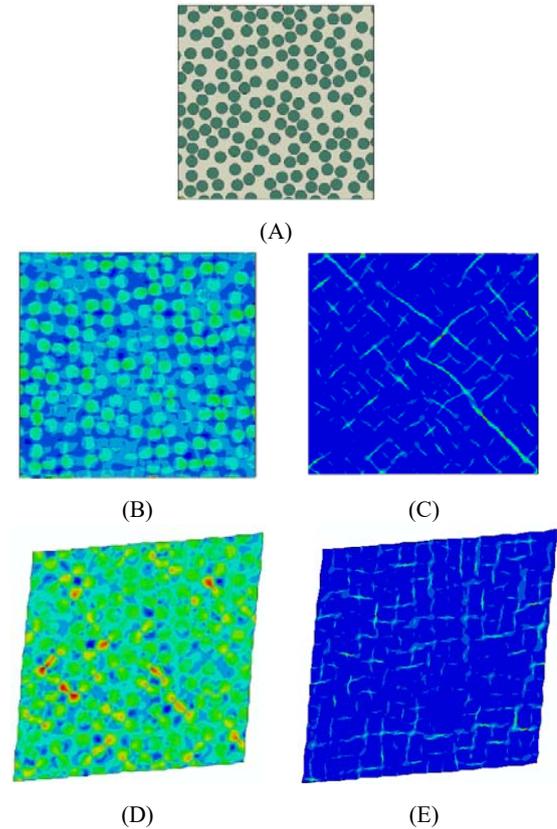


Fig. 6 RVEs with 45% fiber volume fraction (174 Fibers) under normal and shear loading (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

In Fig. 7, the RVE with homogenized material properties, Von-Mises stress and equivalent plastic strain contours are presented for both transverse tension and shear loadings.

For RVEs with random fiber distribution and adequate fiber radii, the Von-Mises stress and equivalent plastic are not maximum just in a part of RVEs but also became to the maximum limit in so many spots. This is a good sign of acceptable fiber distribution.

Fig. 8 shows the transverse stress-strain curves obtained after volumetric homogenization for the fiber distribution. It can be seen that for the volume homogenization element, there is almost no scatter between RVE's and Homogenization curves.

In the next step, the true stress and strain relations described in the previous section are used to introduce the overall equivalent plastic strain and true stress relation. By this equivalent plastic strain and true stress relation, we can model the homogenized material instead of modeling an RVE with 45% fiber volume fraction which is used for the homogenized RVE in this section. Fig. 9 shows the relationship between equivalent plastic strain and true stress for an RVE with 45% fiber volume fraction. The relation between stress and plastic strain is obtained in a good agreement with the input data shown in Table II.

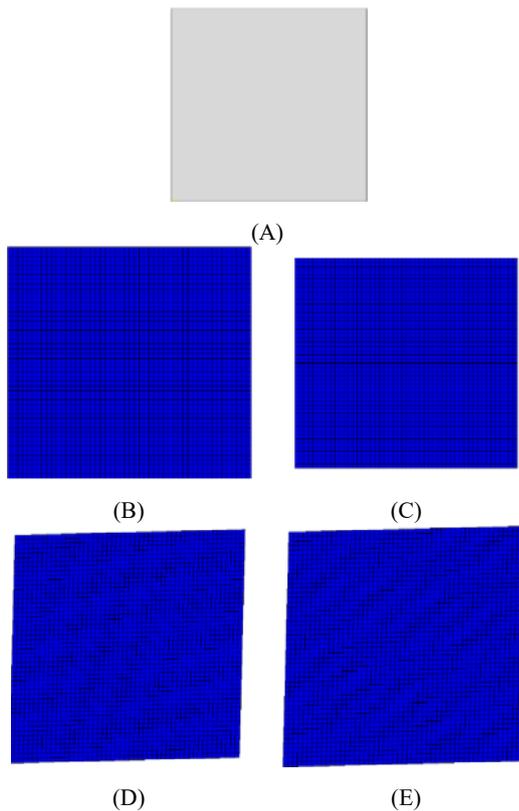


Fig. 7 RVEs with homogenized material properties under normal and shear loading (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

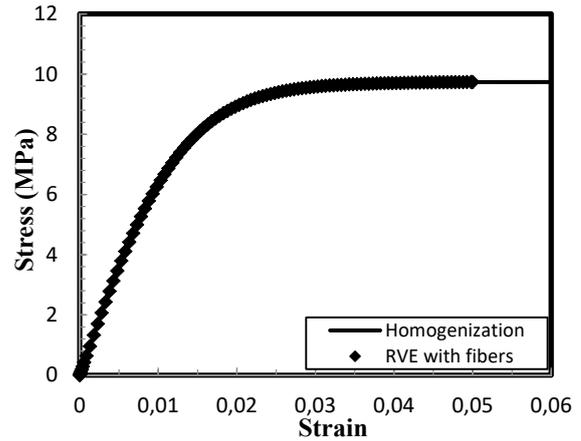


Fig. 8 The transverse stress-strain curves obtained after volumetric homogenization

*B. RVE with 45% Fiber Volume Fraction and a Central Hole*

In this section, we explore the size of RVE for different fiber arrangements and radius sizes. First, we analyzed the response of RVE of fibrous composites with an elastoplastic matrix and elastic fibers, subject to transverse normal and shear loadings. The numerical results obtained by analyzing the 2D RVEs generated with non-uniformly dispersed fibers and fully periodic boundary conditions, for various fiber arrangements and radius sizes, are presented subsequently.

In order to highlight the deformation of the generated RVEs and use of periodic boundary conditions for both normal and shear loading conditions, corresponding Von-Mises stress and equivalent plastic strain contours for all RVEs with non-uniform fiber dispersion are shown in Figs. 10-13. The applied strain for all normal and pure shear loading cases was 0.5%. The deformation of the RVEs reveals the accuracy of the applied PBCs and meshing scheme for both normal and shear loadings. The Von Mises stress contours reveal the expected variability of stress concentrations at the fiber/ matrix interfaces within the RVE resulting from the non-uniform fiber dispersion, while similarly, stress contours corresponding to shear loading simulations reveal the degree of non-uniformity. As it is shown in the figure, the Von-Mises stress and equivalent plastic strain contour maximize in many parts of RVE simultaneously, and that is because of both the high number of fibers in the RVE and the acceptable randomness of distributions. Furthermore, since there is a stress concentration in the each RVEs, the maximum values start in the vicinity of the central hole.

Computed volume averaged in-plane elastoplastic behaviors are compared for all the RVEs in both normal and shear loadings in Figs. 12 and 13. Fig. 12 shows a homogenized model in which only the fibers are omitted during the homogenization process, and the central hole still exists. Another homogenization step is done to eliminate the central hole (Fig. 13). In each homogenized model, different material properties are calculated in spite of the central hole.

Fig. 14 presents the equivalent plastic strain that defines effective material properties by homogenizing fibers and

central hole.

Figs. 15 and 16 present a comparison among computed the graphs of stress-strain values with five randomly generated non-uniform fiber dispersion morphologies and two RVE with two homogenized material properties, for 45% fiber volume fraction under transverse tension and shear loading. A negligible (e.g., 1%) standard deviation for different morphologies existed, demonstrating an excellent conversion in numerical results. The response of random microstructures converges well for large volume element size and predicts a more gradual transition from elastic response to plastic collapse than the simulations conducted on periodic RVEs.

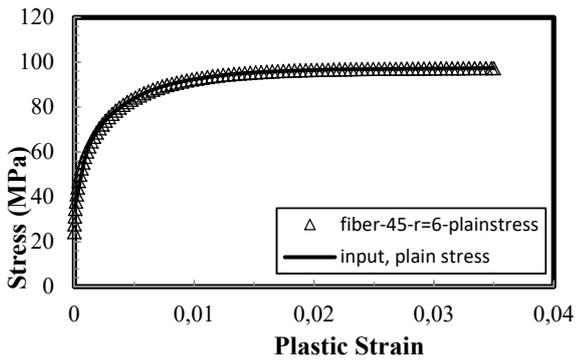


Fig. 9 Equivalent plastic strain and true stress relation for an RVE with 45% fiber volume fraction

We find that the plastic response of the composite is more sensitive to the geometry of the microstructure analyzed than the elastic response. So, a larger RVE is needed to investigate the elastoplastic response of fiber reinforced composite than elastic behavior.

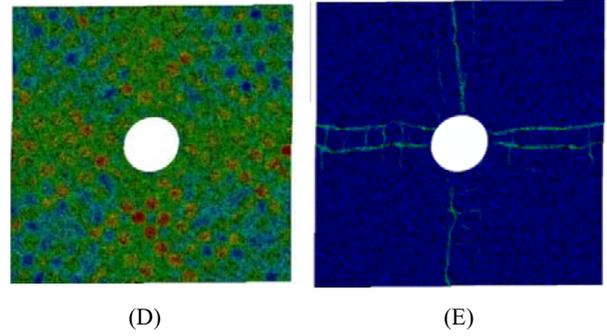
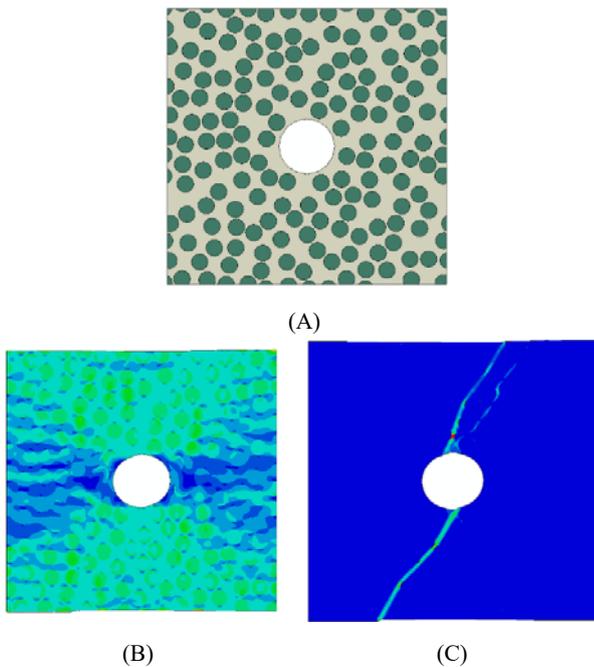


Fig. 10 RVEs with central hole and 45% fiber volume fraction (176 Fibers) under normal and shear loading (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

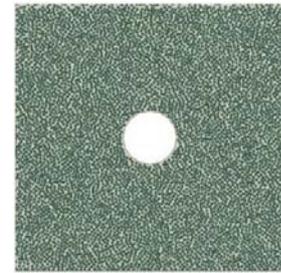


Fig. 11 RVEs with central hole and 45% fiber volume fraction (5718 Fibers) under normal and shear loading, (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

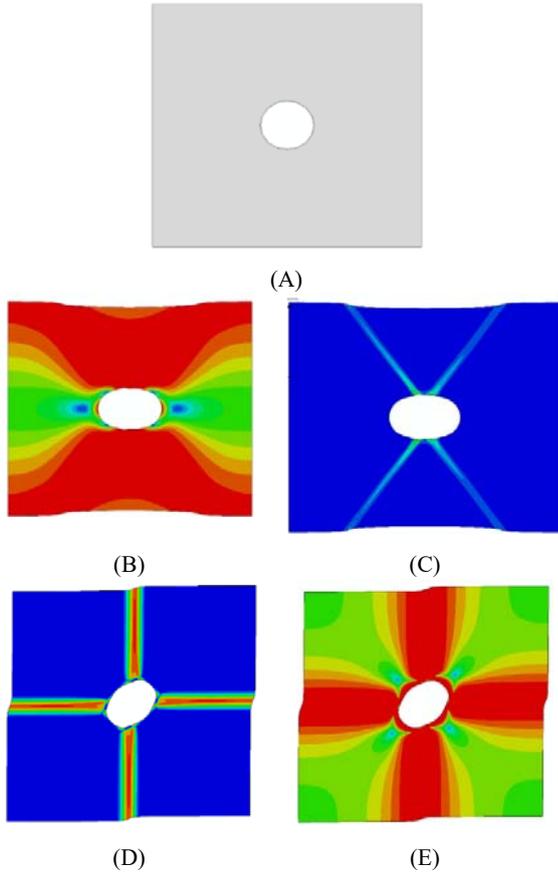


Fig. 12 RVEs with central hole and homogenized material properties under normal and shear loading, (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

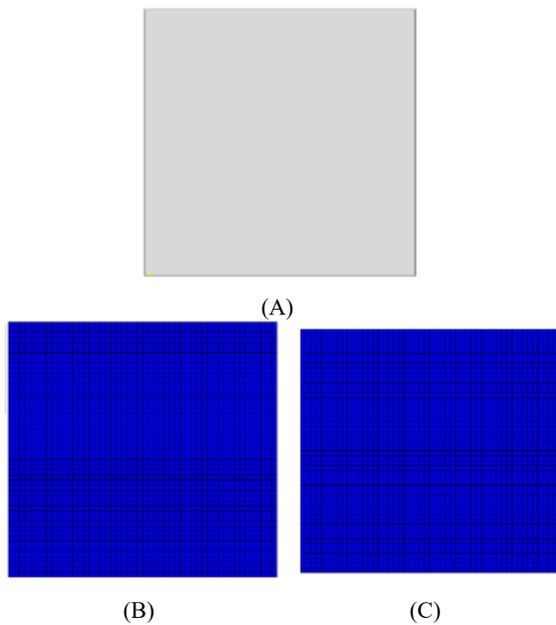


Fig. 13 RVEs with homogenized material properties under normal and shear loading, (A) Modeling RVE, (B) Von-Mises stress contour under normal loading, (C) Equivalent plastic strain contour under normal loading, (D) Von-Mises stress contour under Shear loading, (E) Equivalent plastic strain contour under shear loading

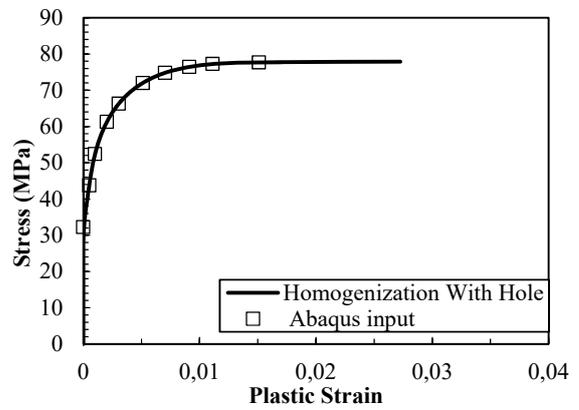


Fig. 14 Validation of the homogenization material properties with input data

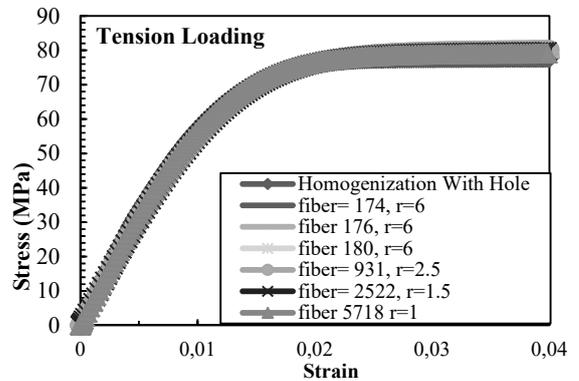


Fig. 15 Stress-strain relationship under tension loading

#### IV. TIME CONSUMPTION (COMPUTATIONAL HOMOGENIZATION OF ELASTOPLASTIC COMPOSITES)

Using such numerical calculations on RVE requires very large memory and time spending. Fig. 17 shows the evolution of the required time as a function of the number of fibers involved in the calculations for a personal computer with core i7 CPU and 8 GB RAM. The worst analysis corresponding to the higher values in time is clearly pointed out (number of fibers=5718). Fig. 17 described the time consumption of micromechanical analyses due to the number of fibers in the

RVEs.

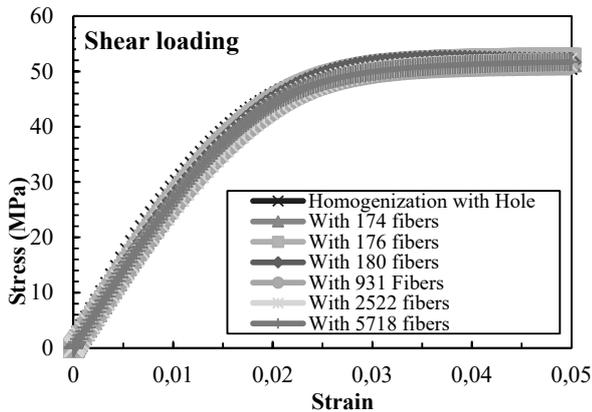


Fig. 16 Stress-strain relationship under shear loading

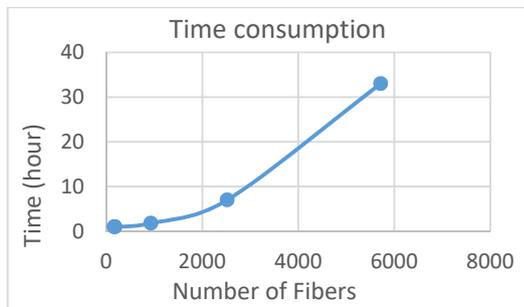


Fig. 17 Time required in hours as a function of the number of fibers

### V. CONCLUSION

The present work investigates the effective properties and the microscopic deformation of the fibrous composite material. The effective material properties are calculated by the homogenization method, and the microscopic deformation is modeled by the FEM for RVEs with arbitrarily fiber distribution and fiber volume fractions. The conclusions can be summarized as follows:

1. For validation, an RVE with resin properties is considered. Different analyses are done under normal and shear loadings and after homogenization, the effective material properties are derived and compared with other literature. The results were in a good agreement.
2. In the next step, some investigations on effective material properties of an RVE with 45% fiber volume fraction with arbitrarily fiber distribution is done. The results obtained by analyzing the model with homogenized material properties are in a good agreement compared to the original micromechanical RVE.
3. A new RVE with a central hole which represents stress concentration is considered next. The effect of stress concentration is investigated with RVEs with different fiber arrangements and radius sizes. Two types of homogenization are done. The first homogenization level is utilized to introduce new material properties instead of fiber and matrix. In the following, the second homogenization level is developed to eliminate the central

hole. In this case, new effective material properties are calculated that replies fiber reinforced composite and also a central hole. In another word, it means a new RVE with only one material can model instead of the RVE with many fibers and a hole.

4. The same procedure is proposed for RVE with several holes to investigate the effect of several stress concentrations. Similar to the previous section, two levels of homogenization are successfully implemented to introduce an RVE with new effective material properties to omit the fibers and holes.

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# Children's Literature As Pedagogy: Lessons For Literacy Practice

Alicia Curtin, Kathy Hall

**Abstract**—This paper explores research and practice shared on a masters University module entitled Children's Literature as Pedagogy. Issues explored include the meaning of childhood and literature; the definition of what counts as text, textual and literacy practice for children and adolescents. A sociocultural framework is used to define literacy practice from this perspective and student voice and experience remains central. Lessons from classroom experience and the use of innovative, multi modal and non traditional texts and pedagogical approaches are offered as examples of innovative and inclusive pedagogy in the field of literacy practice.

**Keywords**—non traditional, pedagogy, practice, sociocultural

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# talk2all: A Revolutionary Tool for International Medical Tourism

Madhukar Kasarla, Sumit Fogla, Kiran Panuganti, Gaurav Jain, Abhijit Ramanujam, Astha Jain, Shashank Kraleti, Sharat Musham, Arun Chaudhury

**Abstract**—Patients have often chosen to travel for care — making pilgrimages to academic meccas and state-of-the-art hospitals for sophisticated surgery. This culture is still persistent in the landscape of US healthcare, with hundred thousand of visitors coming to the shores of United States to seek the high quality of medical care. One of the major challenges in this form of medical tourism has been the language barrier. Thus, an Iraqi patient, with immediate needs of communicating the healthcare needs to the treating team in the hospital, may face huge barrier in effective patient-doctor communication, delaying care and even at times reducing the quality. To circumvent these challenges, we are proposing the use of a state-of-the-art tool, Talk2All, which can translate nearly one hundred international languages (and even sign language) in real time. The tool is an easy to download app and highly user friendly. It builds on machine learning principles to decode different languages in real time. We suggest that the use of Talk2All will tremendously enhance communication in the hospital setting, effectively breaking the language barrier. We propose that vigorous incorporation of Talk2All shall overcome practical challenges in international medical and surgical tourism.

**Keywords**—language translation, communication, machine learning, medical tourism

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# Trends of Change of Political Participation of Young Voters in Indonesia

Najmuddin Rasul

**Abstract**—The purpose of this study is to determine whether media usage and change of citizenship norms influence trends of change of political participation of young voters in Indonesia. The focus of this study is to examine citizenship norms in the context of the development of information and communication technology influence political participation in the context of Indonesia's transition to democracy. The main theoretical framework is media and political participation. For data gathering, 384 young voters between the ages of 17 to 40 years were interviewed in Padang, West Sumatra, Indonesia. The results of this study reveal that gender, age and educational background of respondents did not influence significantly media usage and citizenship norms. The results also show that educational background is not a factor that distinguishes media usage but it becomes differentiating factor in citizenship norms. The results further show that media usage has a significant correlation with citizenship norms and citizenship norms has a significant relationship with political participation. In addition, media usage and citizenship norm significantly influence political participation. The sub-dimensions the citizenship norms (compliance, duty, and engaged citizenship) provides a significant contribution to the sub-dimensions of political participation (traditional political participation, modern political participation, civic political participation). Based on the findings it can be concluded that the political euphoria in the era of transition to democracy has changed pattern of media usage and citizenship norms among the young generation in Indonesia.

**Keywords**—political participation, media, citizenship norms, democracy, young voters, Indonesia

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# The Clash of the Clans in the British Divorce

Samuel Gary Beckton

**Abstract**—Ever since the Scottish Independence Referendum in 2014, there has been a threat of a second referendum. However, if there was another referendum and the majority favoured independence, it is highly likely to be by a small majority. In this paper, it will look into the hypothetical situation of what could have happened if Scotland had voted in favour of independence in 2014. If this occurred, there would be many Unionists within Scotland, including devoted supporters of the Better Together campaign. There was a possibility of some Scottish Unionists not willing to accept the result of the Referendum unchallenged and use their right of self-determination through the UN Charter for their region to remain within the United Kingdom. The Shetland and Orkney Islands contemplated of opting out of an independent Scotland in 2013. This caught the attention of some politicians and the media, via confirming the possibility of some form of partition in Scotland and could have gained extra attention if partition quickly became a matter of 'need' instead of 'want'. Whilst some Unionists may have used petitions and formed pressure groups to voice their claims, others may have used more hard-line tactics to achieve their political objectives, including possible protest marches and acts of civil unrest. This could have possibly spread sectarian violence between Scottish Unionists and Nationalists. Glasgow has a serious issue of this kind of sectarianism, which has escalated in recent years. This is due to the number communities that have been established from Irish Immigrants, which maintain links with Northern Irish loyalists and republicans. Some Scottish Unionists not only have sympathy towards Northern Irish loyalists but actively participate with the paramilitary groups and gave support. Scottish loyalists could use these contacts to create their own paramilitary group(s), with aid from remaining UK (RUK) benefactors. Therefore, this could have resulted in the RUK facing a serious security dilemma, with political and ethical consequences to consider. The RUK would have the moral obligation to protect Scottish Unionists from persecution and recognise their right of self-determination, whilst ensuring the security and well-being of British citizens within and outside of Scotland. This work takes into consideration the lessons learned from the 'Troubles' in Northern Ireland. As an era of 'Troubles' could occur in Scotland, extending into England and Northern Ireland. This is due to proximity, the high number of political, communal and family links in Scotland to the RUK, and the delicate peace process within Northern Ireland which shares a similar issue. This paper will

use British and Scottish Government documents prior to the Scottish referendum to argue why partition might happen and use cartography of maps of a potential partition plan for Scotland. Reports from the UK National Statistics, National Rail, and Ministry of Defence shall also be utilised, and use of journal articles that were covering the referendum.

**Keywords**—identity, nationalism, Scotland, unionism

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# Impact of Newspapers in Society to Eradicate Social Problem: A Study on Triple Talaq Issue in India

Shiwani Kumar

**Abstract**—Newspapers are regarded as the most prior and authentic source of media. In today's era of new media also people rely on the newspapers for authentic information. Newspapers conceptualize the reader's thoughts and beliefs. Newspapers have become the part of people's life which helps to transform and appraise their thoughts regarding current issues. In the proposed research paper the researcher has done the content analysis of leading newspapers of India regarding triple talaq issue as of how the newspapers supported to eradicate this issue and transform the mindsets of public regarding triple talaq. Triple talaq issue in India became very critical concern for the Muslim women of the country and even created Hindu-Muslim riots too. So, the media and newspapers played a major role to bring out the pathetic situation of women and also tried to eradicate the problem through articles and editorials. In the research paper, the researcher has collected 5 samples of articles from leading newspapers of India and tried to analyse the influence of these articles to eradicate the issue.

**Keywords**—triple talaq, newspapers, issue, eradicate, India

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# Comparative Analysis of Photosynthetic and Antioxidative Responses of Two Species of *Anabaena* under Ni and As(III) Stress

Shivam Yadav, Neelam Atri

**Abstract**—Cyanobacteria, the photosynthetic prokaryotes are indispensable components of paddy soil contribute substantially to the nitrogen economy however often appended with metal load. They are well known to play crucial roles in maintenance of soil fertility and rice productivity. Nickel is one such metal that plays a vital role in the cellular physiology, however at higher concentrations it exerts adverse effects. Arsenic is another toxic metalloid that negatively affects the cyanobacterial proliferation. However species-specific comparative responses under As and Ni is largely unknown. The present study focuses on the comparative effects of nickel (Ni<sup>2+</sup>) and arsenite (As(III)) on two diazotrophic cyanobacterial species (*Anabaena doliolum* and *Anabaena* sp. PCC7120) in terms of antioxidative aspects. Oxidative damage measured in terms of lipid peroxidation and peroxide content was significantly higher after As(III) than Ni treatment as compared to control. Similarly, all the studied enzymatic and non-enzymatic parameters of antioxidative defense system except glutathione reductase (GR) showed greater induction against As(III) than Ni. Moreover, integrating comparative analysis of all studied parameters also demonstrated interspecies variation in terms of stress adaptive strategies reflected through higher sensitivity of *Anabaena doliolum* over *Anabaena* PCC7120.

**Keywords**—antioxidative system, arsenic, cyanobacteria, nickel

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# ELT Teachers as Designers of Ubiquitous Learning Experiences

Nadjat Khenioui

**Abstract**—Ubiquitous learning, also known as u-learning, refers to the learner's ability to learn at anyplace at anytime. For it is not classroom-bound only. It breaks through the walls of the classroom to a pervasive setting offering enhanced learning opportunities by engaging in a new world of information sharing and social learning ensured by technology. This paper argues that u-learning represents a new perspective in terms of pedagogy. It shows that teachers can transform today's innovative technology into effective task-oriented learning experiences; promoting learner autonomy, regardless of any geographical or institutional boundaries. This paper undertakes the venture to call attention to the significance use of technology not as an autotelic 'extra tool' to support classroom learning, but in terms of the most exciting affordances for the bottom-up development of materials by teachers via the use of web 2.0 tools, responding, hence, to the demands of pedagogy and didactics of the subject matter.

**Keywords**—educational web 2.0, pedagogy 2.0, experiential learning, ubiquitous knowledge building

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# Malaysian Students' Identity in Seminars by Observing, Interviewing and Conducting Focus Group Discussion

Zurina Khairuddin

**Abstract**—The objective of this study is to explore the identities constructed and negotiated by Malaysian students in the UK and Malaysia when they interact in seminars. The study utilised classroom observation, interview and focus group discussion to collect the data. The participants of this study are the first year Malaysian students studying in the UK and Malaysia. The data collected was analysed utilising a combination of Conversation Analysis and framework. This study postulates that Malaysian students in the UK construct and negotiate flexible and different identities depending on the contexts they were in. It also shows that most Malaysian students in the UK and Malaysia are similar in the identities they construct and negotiate. This study suggests implications and recommendations for Malaysian students in the UK and Malaysia, and other stakeholders such as UK and Malaysian academic community.

**Keywords**—conversation analysis, interaction patterns, Malaysian students, students' identity

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# Experimental Field for the Study of Soil-Atmosphere Interaction in Soft Soils

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**Abstract**—The interaction between atmospheric variables and soil properties is a determining factor when evaluating the flow of water through the soil. This interaction situation directly determines the behavior of the soil and greatly influences the changes that occur in it. The atmospheric variations such as changes in the relative humidity, air temperature, wind velocity and precipitation, are the external variables that reflect a greater incidence in the changes that are generated in the subsoil, as a consequence of the water flow in descending and ascending conditions. These environmental variations have a major importance in the study of the soil because the conditions of humidity and temperature in the soil surface depend on them. In addition, these variations control the thickness of the unsaturated zone and the position of the water table with respect to the surface. However, understanding the relationship between the atmosphere and the soil is a somewhat complex aspect. This is mainly due to the difficulty involved in estimating the changes that occur in the soil from climate changes; since this is a coupled process where act processes of mass transfer and heat. In this research, an experimental field was implemented to study in-situ the interaction between the atmosphere and the soft soils of the city of Bogota, Colombia. The soil under study consists of a 60 cm layer composed of two silts of similar characteristics at the surface and a deep soft clay deposit located under the silky material. It should be noted that the vegetal layer and organic matter were removed to avoid the evapotranspiration phenomenon. Instrumentation was carried on in situ through a field disposal of many measuring devices such as soil moisture sensors, thermocouples, relative humidity sensors, wind velocity sensor, among others; which allow registering the variations of both the atmospheric variables and the properties of the soil. With the information collected through field monitoring, the water balances were made using the Hydrus-1D software to determine the flow conditions that developed in the soil during the study. Also, the moisture profile for different periods and time intervals was determined by the balance supplied by Hydrus 1D; this profile was validated by experimental measurements. As a boundary condition, the actual evaporation rate was included using the semi-empirical equations proposed by different authors. In this study, it was obtained for the rainy periods a descending flow that was governed by the infiltration capacity of the soil. On the other hand, during dry periods. An increase in the actual evaporation of the soil induces an upward flow of water, increasing suction due

to the decrease in moisture content. Also, cracks were developed accelerating the evaporation process. This work concerns to the study of soil-atmosphere interaction through the experimental field and it is a very useful tool since it allows considering all the factors and parameters of the soil in its natural state and real values of the different environmental conditions.

**Keywords**—field monitoring, soil-atmosphere, soft soils, soil-water balance

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# MOCVD Overgrowth on the Bragg Grating for Gallium Nitride Based Distributed Feedback Laser

J. Z. Li, M. Li

**Abstract**—Laser diodes fabricated from the III-nitride material system are emerging solutions for the next generation telecommunication systems and optical clocks based on Ca at 397nm, Rb at 420.2nm and Yb at 398.9nm combined 556 nm. Most of the applications require single longitudinal optical mode lasers, with very narrow linewidth and compact size, such as communication systems and laser cooling. In this case, the GaN based distributed feedback (DFB) laser diode is one of the most effective candidates with gratings are known to operate with narrow spectra as well as high power and efficiency. Given the wavelength range, the period of the first-order diffraction grating is under 100 nm, and the realization of such gratings is technically difficult due to the narrow line width and the high quality nitride overgrowth based on the Bragg grating. Some groups have reported GaN DFB lasers with high order distributed feedback surface gratings, which avoids the overgrowth. However, generally the strength of coupling is lower than that with Bragg grating embedded into the waveguide within the GaN laser structure by two-step-epitaxy. Therefore, the overgrowth on the grating technology need to be studied and optimized.

Here we propose to fabricate the fine step shape structure of first-order grating by the nanoimprint combined inductively coupled plasma (ICP) dry etching, then carry out overgrowth high quality AlGaIn film by metalorganic chemical vapor deposition (MOCVD). Then a series of gratings with different period, depths and duty ratios are designed and fabricated to study the influence of grating structure to the nano-heteroepitaxy. Moreover, we observe the nucleation and growth process by step-by-step growth to study the growth mode for nitride overgrowth on grating, under the condition that the grating period is larger than the mean migration length on the surface. The AFM images demonstrate that a smooth surface of AlGaIn film is achieved with an average roughness of 0.20 nm over  $3 \times 3 \mu\text{m}^2$ . The full width at half maximums (FWHMs) of the (002) reflections in the XRD rocking curves are 278 arcsec for the AlGaIn film, and the component of the Al within the film is 8% according to the XRD mapping measurement, which is in accordance with design values. By observing the samples with growth time changing from 200s, 400s to 600s, the growth model is summarized as the follow steps: initially, the nucleation is evenly distributed on the grating structure, as the migration length of Al atoms is low; then, AlGaIn growth alone with the grating top surface; finally, the AlGaIn film formed by lateral growth. This work contributed to carrying out GaN DFB laser by fabricating grating and overgrowth on the nano-grating patterned substrate by wafer scale, moreover, growth dynamics had been analyzed as well.

**Keywords**—DFB laser, MOCVD, nanoepitaxy, III-nitride.

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# Hyper-Local News Portals in Germany: An Economic Analysis

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**Abstract**—Hyperlocal news portals are increasingly replacing the gaps that traditional publishers have left behind by withdrawing from the local. But many hyper-local news portals face economic difficulties. The present study examines the economic situation of such portals in Germany via an online survey and makes proposals to increase profitability. The data shows that there is a broad range of hyperlocal portals operating in Germany. They use different business models and only a smaller part of them run their hyperlocal portal as a profitable business.

**Keywords**—Alternative and community media, economic analysis, hyper local media, journalism, new media, survey.

## 1. Introduction

A growing number of editors and reporters lost their jobs, local editorial offices are merged or even completely closed, newspapers are shut down and consequently the concentration on the local newspaper market continues to increase (Reißmann, 2010, Röper, 2014, p. 255, Schütz, 2012, 571 & 580; Weichert, 2013, p. 61).

The answer to this negative trend may come from overseas. Particularly in the US, hyper-local news portals, providing information to small, geographically limited communities have been gaining in popularity for several years. Already in 2007, the American journalist Will Bunch (2007, p. 29) claimed: "journalism will die if it does not become more local, or even something called 'hyper-local'". For this reason the central question of this research paper is: Are such alternative community media outlets successful from an economic point of view?

The present study tries to answer this question and deals with media-economic questions of alternative hyper-local news portals in Germany. Above all, the study attempts to at least partially close the gap in research on the topic in Germany and to pave the way for further studies.

## 2. Literature Review: The phenomenon of hyper-locality in the US and Europe

Due to the increased emergence of such portals they became a subject of investigation of US-American social scientists. In 2007, Schaffer (2007) identified around 500 hyper-local portals, 31 of them were investigated by in-depth interviews and another 191 through an online survey. He described the new journalistic phenomenon "as a form of, bridge'-media, linking traditional forms of journalism with classic civic participation" (Schaffer, 2007, p. 7). Two years later, it was recognized that such community and local news portals could play an important role in preserving democracy (Downie & Schudson, 2009).

Cook, Geels & Bakker (2016) reported in a recent research report of the foundation Nesta about hyper-local portals in Europe in terms of their revenue and revenue models. In the context of case studies, a content analysis of 35 portals from Great Britain, the Netherlands, France, Belgium and Sweden had been carried out.

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The results provided the first broader insights into the revenue opportunities of such platforms.

## 3. Media economic perspective / Theoretical approach

The reasons for the increasing economisation of the media sector are extremely complex and above all based on changes in society, market structures and market behavior (von Rimscha & Siegert, 2015, pp. 60ff.). Particularly with regard to journalism, this advancing economization process is often viewed critically.

The present study is based on a microeconomic market analysis that examines key criteria of hyperlocal news portals. The goal is to describe key parameters of the portals to establish market transparency in terms of structure and size of the players (Thommen/Achleitner 2012: 153; Meffert 2012; Esch/Hermann/Sattler 2011).

## Research gap

The relevance of an economic investigation of this topic is made clear by the fact that most of the previous studies have dealt exclusively with the content of hyper-local portals. As Kurpius, Metzgar & Rowley (2010, p. 363) state, "Much of the existing literature examining hyper-local media operations focuses more on how and why these entities have come to exist rather than on how they are structured and funded and whether they are sustainable for the long term". While this has at least partially changed in the US and some European countries in recent years, there are no in-depth insights into the economic situation of such portals regarding Germany.

## 4. Methodological approach

### 4.1 Definition of the subject of investigation

Hyper-local news portals are understood as Internet platforms that offer news or other content or services to people in a particular geographic area. These can be neighborhoods, towns, city districts or whole cities. They operate economically independently of local or regional newspaper publishers, large media companies and government institutions. Further prerequisites to be included in the sample were the criteria of universality and timeliness, but both were interpreted in a broad sense.

### 4.2 Research Method

A standardized online survey was sent to 289 German hyper local portals. The questionnaire included 29 questions which were subdivided into different thematic sections.

Basics, Organization and workflows, Financing and turn over, Staffing situation and costs and Sustainability and Future Plans. On June 27th 2017 the survey was sent out. During a period of two week 67 respondents completed the questionnaire (23.2 %).

## 5. Central research questions and results

The following central research questions could be answered:

- What size and shape do hyper-local news portals have?
- How is the personnel situation of hyper-local news portals?
- Which revenue and financing models have hyper-local news portals?
- Which future plans do the operators of such portals pursue?

## 6. Relation to Community communication and Alternative Media

Alternative community media play an important role in modern societies. Their journalistic achievements are largely recognized,

but what makes them economically successful or maintains their operations, is hardly explored. This study sheds some light on how alternative community media could preserve or even expand their range of activities.

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