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# Students' Consciousness of their Problem Solving Approaches as a Key to Creativity in Design

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## Abstract

Architectural engineering students are constantly dealing with ill-defined and tangled design problems. Many scholars accentuated the importance of creative thinking in tackling such wicked and complex problems. Accordingly, getting engaged in an ill-defined problem solving process requires specific personality traits that are often critical to creativity and innovation in design. In that sense, architectural engineering curricula need to provide various strategies through which such individual skills can be nurtured and developed. The objective of this study is to empirically identify the different patterns of students' approaches in solving problems and the role of group discussions in such a process. The study adopted a qualitative approach, in a live class setup, through a series of workshops to allow for in-depth exploration of the students' problem solving skills and abilities. The intention is to help students in discovering and in being aware of their own way of solving problems and identifying its strengths and weaknesses. This is considered a core and significant step towards the improvement and development of their design thinking skills. The findings of the study have emphasized the positive impact of the cyclical behavior in the creative problem solving process and highlighted the different key issues and lessons emerging from students' consciousness of the mental processes that occurred during this iterative process. Such awareness and consciousness of those emergent issues is expected to encourage conscious design, increase tolerance for ambiguity and improve self-confidence which are believed to dramatically help students in creatively solving ill-defined architectural design problems.

**Keywords:** problem solving, individual skills, creativity, design thinking, ill-defined problems, design education, architectural design; students' awareness, conscious design, Geneplore model

## 1 Introduction

In architecture, designers are constantly dealing with wicked, tangled and ill-defined design problems (Buchanan, 1992; Rittel, 1972; Schumacher, 2012). Addressing such complex problems call for creative thinking in order to be able to solve them (Hocking & Vernon, 2017). Getting involved and immersed in an ill-defined and intricate design problem solving process requires an immense cognitive and mental effort, courageous behavior, high tolerance to ambiguity and self-confidence (McAdam & McClelland, 2002; Paletz & Peng, 2009; Reiter-Palmon & Illies, 2004). In that sense, fostering creativity in engineering and design education to enable students to develop as creative designers is quite inevitable (Baillie, 2002; Lau, 2017). Preparing them to be future professional designers necessitates the implementation of practical steps that make creativity an integral part of the architectural curricula (Kowaltowski, Bianchi, & de Paiva, 2010). However, many scholars highlighted the fact that education programs for development of creativity in design education are quite scarce and not provided sufficiently (Baillie, 2002; Bourgeois-Bougrine, Buisine, Vandendriessche, Glaveanu, & Lubart, 2017; Cho, Hong, & Kwang-Soo, 2016).

Therefore, different educational institutions are expected to provide various means and strategies to couple creativity and design education. In an attempt of improving and developing the students' design thinking and cognitive skills, the study aims to investigate the different students' approaches in solving problems through a series of workshops in a course entitled AR221 Scientific Thinking in the Department of Architectural Engineering and Environment Design at the Arab Academy for Science, Technology and Maritime Transport (AASTMT), Cairo, Egypt. This allows for an in-depth exploration of the students' problem solving skills and abilities, identifying their strengths and weaknesses.

The study raises a set of questions that can be summarized as follows:

- Are students aware of their own way of solving problems?
- Can this awareness and consciousness of the mental processes occurring in problem solving help them in the development and improvement of their design thinking skills?

To answer the questions and meet the objective, the study adopted a qualitative approach, in a live class setup, through two different workshops. The study employed a variety of data gathering tactics and methods to allow for data triangulation.

## 2 Creativity in Problem Solving: A Cognitive Perspective

There are a variety of approaches that tackle creativity from different perspectives. Many scholars addressed this issue and worked on the categorization of the different approaches and paradigms to creativity. Sternberg and Lubart (1999) discussed creativity in terms of six different approaches: mystical, psychoanalytic, pragmatic,

psychometric, cognitive and social-personality approaches. They concluded that another confluence approach, a multidisciplinary one, in which different paradigms and components of creativity can converge is required.

Consequently, a categorization that is based mainly on the work of Taylor (1988), Sternberg and Lubart (1999), and Villalba (2008) was proposed (Cachia, Ferrari, Ala-Mutka, Punie, & Institute for Prospective Technological Studies, 2010). Their categorization included five main approaches: psychometric, psychoanalytic, self-expression and mystical, end-product and cognitive approaches. To them, the cognitive approach embraces phase oriented studies, pragmatic methods and thinking theory. More precisely, it is considered as an umbrella term under which several original paradigms such as pragmatic, cognitive and social-personality approaches are combined.

The perspective proposed by Cachia et al. (2010) in understanding the cognitive approach in a multi-disciplinary nature is quite relevant to this study, which is in an educational context, for various reasons: 1) it addresses creativity as a process and in education, emphasis on the process should be always given a top priority (Cachia et al., 2010); 2) it considers creativity as a skill and accordingly can be developed and nurtured especially in educational and learning environments (Edward de Bono, 2007, 2009); 3) this multi-disciplinary approach is in a sense a step towards implementing different ways and strategies of learning appropriate to each person (Gardner, 1999). Therefore tackling creativity from an inclusive cognitive perspective that involves phase oriented studies, pragmatic methods and thinking theories is the main focus of this study.

There are diverse well known phase oriented studies that deal with the different steps and stages of the creativity process such as the model of Wallas (1926) and the Geneplore model (Finke, Ward, & Smith, 1992). This study focuses on the Geneplore model, which is not linear in nature, because of its relevance to the engineering design cycle and this can help in developing the design thinking skills of architectural engineering students. As implied by its name, the Geneplore model divides the process of creativity into a generation phase and exploration phase (Finke et al., 1992) . The model accentuates the dynamic nature of the mental processes that might occur in a back and forth behavior throughout the problem solving process. If the output is non-satisfactory a return to the generative phase is encouraged (Fig. 1). Regarding pragmatic methods, creativity is developed through different techniques and methods, such as those proposed by Edward de Bono, who is a leading figure in this approach. His tools and methods are used to develop lateral thinking skills and to broaden one's perception of a matter (Edward de Bono, 1970, 1991, 2000, 2007). In addition, thinking theories focus on how personality traits and environmental factors are related to creativity (Cachia et al., 2010). Such theories highlight the importance of several personality traits such as self-confidence, attraction to complexity, risk taking, self-efficacy, willingness to overcome obstacles and tolerance for ambiguity to creativity (Gardner, 1999; Sternberg & Lubart, 1999).

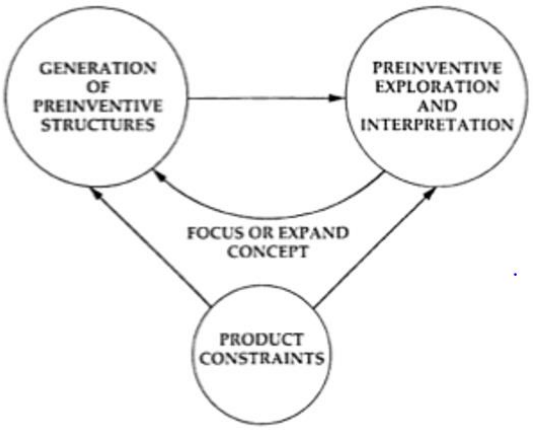



Fig. 1. The basic structure of the Geneplore model (Finke et al., 1992)

Based on the above review of the different schools of thoughts within the inclusive cognitive approach (Cachia et al., 2010), one can conclude the commonalities and overlaps between them. They all focus on the essence of creativity as a process rather than supporting the notion that creativity comes suddenly and unexpectedly. Accordingly, this study tackles creativity in problem solving from this cognitive perspective. It was conducted in a live class setup where students were engaged in different workshops and exercises that are based on pragmatic methods. An in-depth exploration of the students' problem solving skills during the generation, exploration and modification phases was conducted. Reflection and insights of such investigations and its impact on their personality traits were concluded.

## 3 Methodology

The objective of this study is to identify the different patterns of students' approaches in solving problems and the role of group discussions in such a process. The participants in this study are students who are enrolled in a course entitled AR221 Scientific Thinking[1] in the Department of Architectural Engineering and Environment Design at AASTMT. The intention is to help students in discovering their own way of solving problems and identifying its strength and weakness. This is considered as a significant step towards the improvement and development of their design thinking skills.

### *3.1 Research Design*

The study adopted a qualitative approach in a live class setup to allow for in-depth exploration of the students' problem solving skills and abilities. Such a live setup helps in understanding the phenomenon under investigation in the typical complex and messy

[1] This course, in its current status, has been designed, developed and taught by the author since fall 2008.

setting of a semester with all the normal pressures associated with it (Taborda, Chandrasegaran, Reid, Ramani, & Kisselburgh, 2012). The study relies on the analysis of two different workshops. The data collection draws from different sources such as oral and written students' reflections and insights, the author's observational field notes, photographs, videos, audio recordings and samples of students' work.

### *3.2 Description of the Context and Workshops*

The study was conducted in fall 2019 and 42 students in two different classes, 21 per each, were involved. It focuses on the analysis of two different workshops in which different exercises were conducted. The exercises are inspired from and based on original problems proposed by Edward de Bono (1991).

The first workshop was held on two consecutive sessions with a total duration of four hours. Most of the students were working in pairs constituting 23 groups numbered from 1 till 23. In this exercise, students were required to create abstract compositions according to a set of constrains that increase in complexity from one step to another using six identical block-shaped objects[2].

The second workshop was held over a two-hour session. Students were working in groups composed of 4 – 5 students, with a total of 10 groups labeled from A to J. In this exercise, students were required, in two different problems[3], to place the bottles of water on a flat surface and the distance between each of them should be slightly more than the length of a linear flat element, in this case wooden tongue depressors were used. Using a maximum of four tongue depressors, they should construct a platform on top of the bottles and it ought to be strong enough to support a full plastic bottle of water.

By analyzing the work conducted and the mental processes involved during the problem solving process in the above workshops, the research is expected to answer the following questions:

- What are the different classifications of solutions and patterns of students' approaches in solving problems?
- What are the key issues and lessons emerging from students' consciousness of the mental processes that occurred during the cyclical problem solving process?

## 4 Analysis and Discussion

During the different workshops and exercises, which were based on pragmatic methods and techniques, multiple Geneplore cycles occurred and in fact one cycle informed the

[2] Problem 1: arrange the six blocks so that each touches two and only two other blocks; problem 2: arrange the six blocks so that each touches three and only three other blocks; problem 3: arrange the six blocks so that each touches four and only four other blocks; problem 4: arrange the six blocks so that each touches five other; problem 5: arrange the six blocks in the following fashion (one block must touch only one other, one block must touch only two others, one block must touch only three others, one block must touch only four others, one block must touch only five others.

[3] First problem in this exercise was to use three bottles where each bottle forms the corner point of a triangle of equal sides; second problem in this exercise was to place four bottles where each bottle is placed at the corner of a square.

other. Encouraging students to alternate between generation and exploration has resulted in a significant improvement in the solutions and alternatives proposed by the students. This is quite consistent with the findings of Finke et al. declaring that "This cycling between the phases of generation and exploration typically occurs when people engage in creative thinking" (Finke et al., 1992, p. 18).

In this qualitative study, there was extensive verbal and visual material, in the form of oral and written students' reflections and insights, the author's observational and field notes and samples of students' work. A classification, sorting and categorization task was conducted to analyze this material in order to understand the reasons behind such a significant improvement in results. During this analysis process, close scrutiny helped in identifying the different categories of solutions and patterns of students' approaches in solving problems. Moreover, abstracting out assisted in capturing the common recurring ideas and themes which has led to the extraction of different key issues and lessons emerging from students' consciousness of the mental processes that occurred during this cyclical process.

The following part will discuss those different categories and patterns of problem solving and the emergent lessons highlighted while relating them to the relevant literature and previous studies. The findings of this qualitative study will be supported by quotations, observational notes along with case descriptions selected from the work of students.

### *4.1 Classification of the Different Students' Solutions and Alternatives*

In digging deep trying to understand what happened during this cyclical problem solving process, different patterns and approaches of solving problems were discovered and solutions can be grouped and classified as follows:

#### *4.1.1.Incorrect Trials Leading to Valid Solutions*

It was observed that many students arrived at a valid solution through incorrect trials (or with the help of incorrect trials). Through trial and error, they concluded that it is not a must to change the whole idea, sometimes developing and modifying it leads to the required results. One of the students telling his colleague while looking at the alternative "We do not have to start from scratch, we can modify the existing incorrect solution and try to make it fit the given criteria" and finally they were able to rectify it (Fig. 2). Many students comprehended the vital role of incorrect trials in proposing valid and interesting solutions and how failure can inform success.

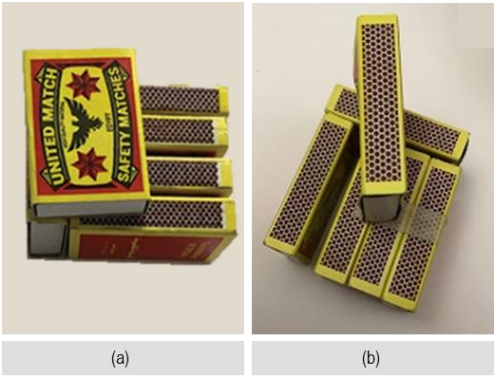
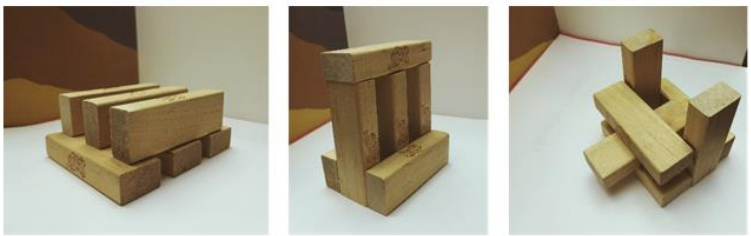



Fig. 2. An example showing (a) an incorrect trial leading to (b) a valid solution by experimenting through subtracting, displacing, flipping and rotating *(workshop one, problem 5, group 13)*

### *4.1.2. Simple Valid Solutions Turning to Complex Solutions*

After arriving at valid solutions that fit the criteria of a given problem, some students who were still provoked to propose more creative alternatives started to dig in more. They tried to explore with different directions, orientations, positions, visual inertia, degrees of stability and surface area. For example, one of the groups presented some horizontal and vertical alternatives and they were even more challenged and tried to merge the horizontal and vertical treatments in addition to changing the stability and visual inertia of the compositions generating more complex solutions (Fig. 3). In another exercise, and through play and discovery, a group initially proposed an alternative in which they were able to lift the weight using the four wooden tongue depressors and placing the bottle with a small surface area, then a much smaller area on the platform (Fig. 4a and 4b). They were provoked and extremely engaged and tried to use only three sticks to lift the weight and they succeeded; surprisingly they decreased the surface area of the weight on the platform again until they were able to balance it (Fig. 4c and 4d). In general, this provocative and generative behavior has resulted in restructuring of the existing patterns and accordingly synthesizing it into new ones creating more complex and interesting alternatives.



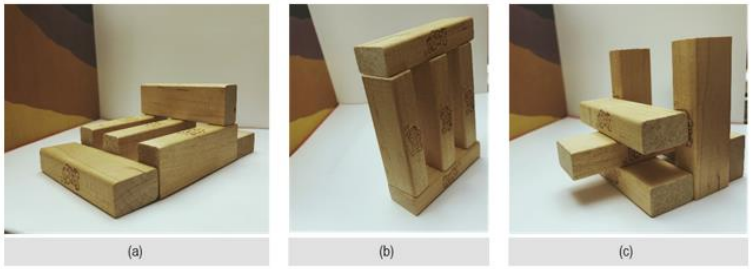



Fig. 3. An example showing simple valid solutions turning to complex solutions through experimenting (a) horizontally, (b) vertically and (c) merging horizontal and vertical solutions to generate new alternatives *(workshop one, problem 2, group 14)*

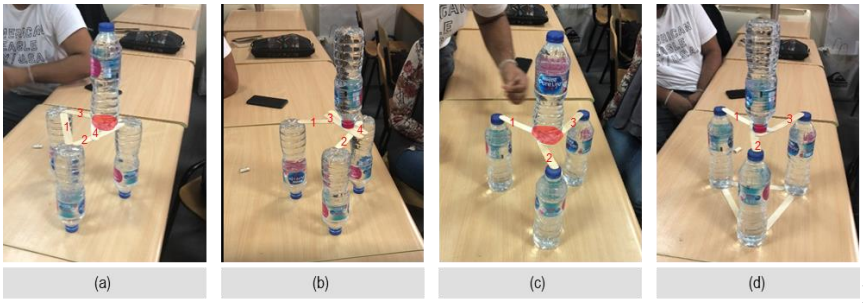



Fig. 4. Attraction to complexity through lifting the weight on the platform (a) using the four tongue depressors on a small surface area, (b) using the four tongue depressors on a much smaller surface area, (c) using only three tongue depressors on a small surface area and (d) using only three tongue depressors on a much smaller surface area *(workshop two, problem 1, group F)*

### *4.1.3. Solutions that Meet the Criteria Becoming Solutions that Exceed the Criteria*

Some students were able to take the challenge even further than just meeting or satisfying the given constrains or rules. For example, they started to imagine, associate and link their abstract compositions to the surrounding environment (Fig. 5a). Others modified their alternatives trying to re-structure it in order to fulfill another self-imposed criteria (Fig. 5b). Others started to specifically relate and tie to different architectural phenomena, concepts and ideas such as cantilevers, voids and orientation in architecture (Fig. 5c). Furthermore, one of the groups not only associated to architecture by mentioning that the composition resembles a pathway, but also has modified the composition through shifting to enhance the proportions, enclosure, illumination and depth of the space creating a more complicated and innovative solution (Fig. 5d). In addition, some students tested the stability of the proposed platform not only through the given weight, full plastic bottle of water, but also by applying additional weights to the original one (Fig. 6).


Fig. 5. Sample of students' work taking the challenge beyond the given constrains or rules (a) associating and linking their abstract compositions to the surrounding environment *(workshop one, problem 2 and 3, group 4),* (b) modifying the valid alternative trying to restructure it to generate a composition with a base, body and a cover in addition to meeting the original criteria *(workshop one, problem 3, group 9),* (c) developing a static solution to a dynamic self-supported structure, referring to it

as cantilevered blocks, and imagining it as an architectural composition that is sitting lightly on the ground *(workshop one, problem 1, group 1)* and (d) imagining the abstract composition as a pathway, and accordingly shifting one of the blocks backwards to enhance proportions, enclosure, illumination and depth of the space *(workshop one, problem 1, group 17)*

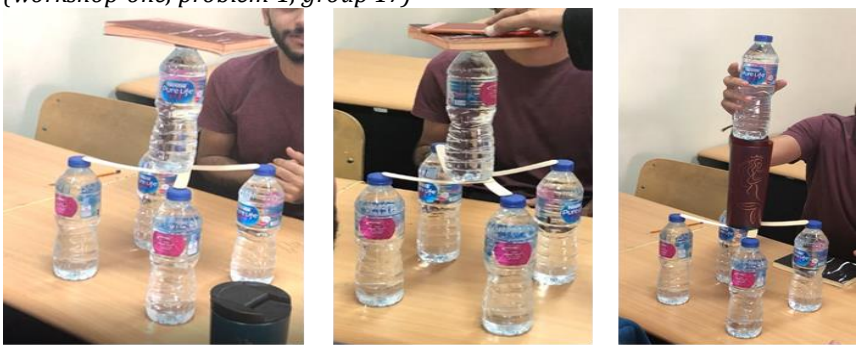



Fig.6. Experimenting and playing with extra weights to test the stability and strength of the platform (a) adding a notebook, (b) adding a notebook and a mobile phone and (c) full car mug in addition to the bottle *(workshop two, problem 2, group H*

### *4.2 Key Issues and Lessons Emerging from Students' Consciousness of the Cyclical Problem Solving Process*

The analysis revealed four key issues and lessons emerging from students' awareness of the mental processes that happened during the cyclical problem solving process: experimentation and discovery, challenging the obvious, discussion and collaboration and deferring early judgment.

#### *4.2.1. Experimentation and Discovery*

Nearly, all the students have valued the importance of experimentation in the creative problem solving process and considered it as an integral part of the process. They understood the critical role that many operational verbs, such as trying, retrying, flipping, shifting, rotating, mixing, merging and integrating, play in proposing innovative solutions. Based on the analysis, many of those operations and experimental approaches done by students, yielded outstanding results. Through experimentation and discovery, they were able to generate, explore, modify, develop, diversify, fine tune and refine their outcomes. Some students were unable to find an alternative that fulfils the given criteria and through trial and error they were able to arrive at valid solutions (Fig. 7). Others were able, through play, to arrive at a solution adopting a sequential manner and based on this they were able to figure out a rule through which an infinite number of alternatives were generated (Fig. 8). Those who were not satisfied with their simple proposals kept trying and experimenting in order to discover new approaches and possibilities. As emphasized by Michalko (1991), a simple or mild change stimulated and provoked an endless number of ideas. This change might be in relational properties such

as orientation, visual inertia, and position (Fig. 9a), or could even be in the nature, material or type of objects used. Change in visual inertia, degree of stability and balance of a composition with an identical arrangement yet a different object was observed, creating an interesting diversity in the proposed solutions (Fig. 9b).

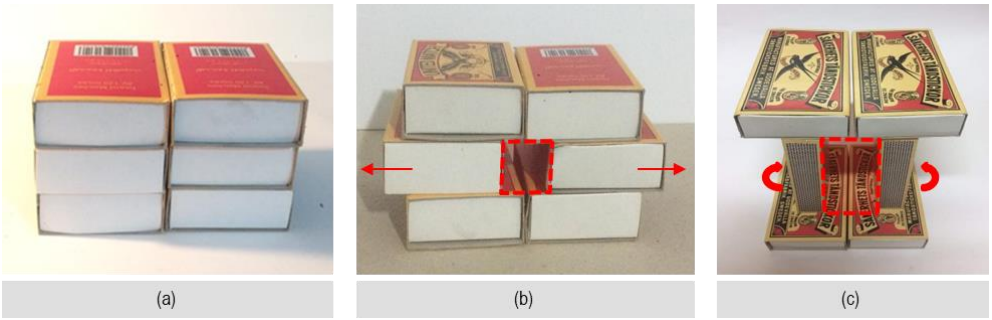



Fig.7. Fixing an (a) incorrect alternative through shifting to (b) create voids generating a valid solution in addition to (c) changing the proportions of the void, through rotating and flipping, creating a new alternative (*workshop one, problem 1, group 11*)

It was observed that play, fun and free investigations were always involved when a better solution was proposed by students. This is consistent with numerous studies arguing that students are deeply engaged in a learning environment that encourages play, discovery and having fun (Carroll & Thomas, 1988; Taborda et al., 2012). For example, one of the groups used different objects to test the strength of the platform. They started with a light object and when they succeeded they placed the given weight showing that they gradually became more confident (Fig. 10). Another group was experimenting and playing with extra weights to further test the stability and strength of the platform. Not only were they using different objects as extra weight to add more complexity to the challenge, but they also used precious objects such as mobile phones showing increased self-confidence and high inclination towards risk taking (Fig. 11).

Adopting a loose attitude, as referred to by Lin (1993), rather than a tight one and a willingness to try and re-try and see a mistake as something positive is greatly important to develop as creative thinkers and designers. Fostering an environment for creative work requires providing a balance between structure and free investigation, encourages play and fun methods and emphasizes the importance of reflection and iteration (Edward de Bono, 1991; Puja Khatri & Sumedha Dutta, 2018).

According to Cross (1999), design is opportunistic and exploratory in nature and cannot be predicted or anticipated in advance. Thus, a creative designer needs to think about what might lie ahead, discover something new instead of recycle something that he/she already knows. This confirms the importance of experimentation and discovery to creative problem solving in design and how it helps in improving self-confidence, encourages risk taking and enhances tolerance for ambiguity and they are all critical to creativity in design (Cross, 1999).


Fig.8. Figuring out a general rule (a) proceeding in a sequential manner, (b) and accordingly an infinite number of alternatives was generated (*workshop one, problem 5, group 18*)

### *4.2.2. Challenging the obvious*

It was found that raising questions was extremely helpful in the problem solving process. According to Michalko (1991), questions stretch one's eyes wide open. Questions helped in viewing the challenges from different perspectives, thus introducing new possibilities. This was either achieved through an insight which was quite rare, or mainly through critically revisiting and analyzing their proposed alternatives. Some students started to group and classify their proposals highlighting similarities and accordingly concluding the self-imposed constrains that they were imprisoned by and consciously started to challenge them. For example, they started wondering does it necessarily have to be a loop! Why not vertical? Should it be only orthogonal? Why symmetrical? In addition to many other similar questions (Fig. 12a, 12b and 12c). In other cases, students tried to analyze their incorrect trials, what didn't they try, challenging how else and what else is missing (Fig. 12d).

This curious and skeptical behavior allowed students to reverse the different conventional assumptions that they have subconsciously imposed on themselves, and this in turn, has helped them not only in generating and developing their proposals but also in proposing unique ideas and breakthroughs. Based on this, most of the students became more attracted to complexity, patient even if they do not know the answer yet and more willing to overcome any obstacles. They, as emphasized by Edward de bono

(1970), started to use provocative manners instead of simple ones and believed that no matter how good something is, there is always a potential of doing it better.

As a reflection, being skeptical and challenging the obvious along with how this positively affects the tolerance to ambiguity and willingness to overcome problems is very important in addressing architectural design problems. The design process is an indeterminist one, as referred to by Goldschmidt (1997), which is characterized by uncertainty and ambiguity (Cross, 1999) and thus requires such skills. Preconceptions and prejudgments are issues that need to be widely addressed in design education (Kowaltowski et al., 2010). Liberation from conventional assumptions and preconceptions help designers to expand their possibilities. Although this is quite overwhelming for designers, yet this leaves many options open for as long as possible and that is a merit that usually leads to creative and successful designs.

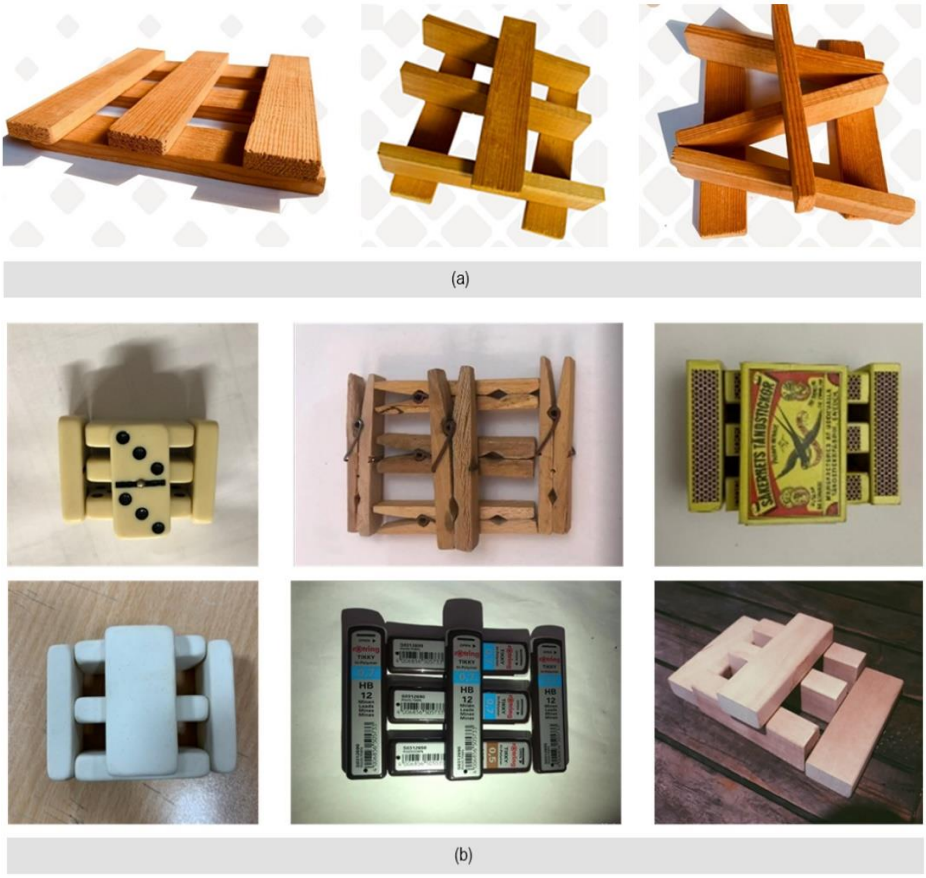



Fig.9. Simple change stimulating and provoking new ideas (a) change in position, visual inertia and orientation leading to more dynamic alternatives *(workshop one, problem 2, group 15)* (b) experimenting and playing with different objects and observing the change in

visual inertia, degree of stability and balance of the compositions (*workshop one, problem 5, group 5*)


Fig.10. Testing the stability and strength of the platform (a) first using a light object (wallet) (b) using the given weight (bottle) showing gradual increase in self-confidence *(workshop two, problem 1, group C)*

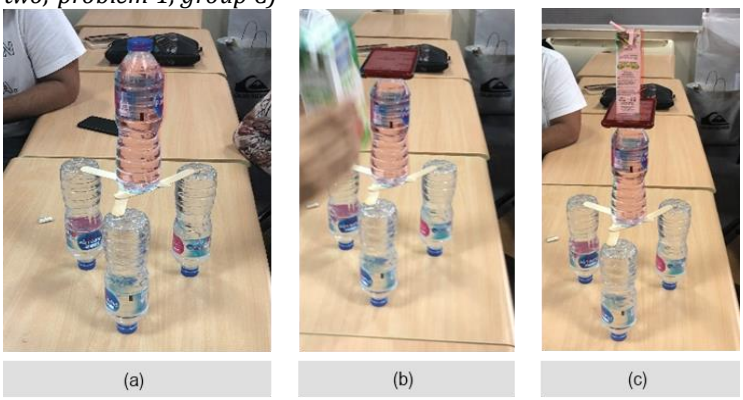



Fig.11. Testing the stability and strength of the platform (a) using only the given weight (bottle), (b) using the given weight (bottle) and a mobile phone, (c) using the given weight (bottle), a mobile phone and on top of it, a small juice box showing increased self-confidence and high inclination towards risk taking *(workshop two, problem 1, group F)*

### *4.2.3. Discussion and Collaboration*

Based on the students' reflections and the author's observations, collaboration, discussion and free-wheeling were very useful and helped many students to arrive at their solutions or even develop them. While working in pairs, during the first workshop, several groups have highlighted the importance of discussion in the problem solving process. One of the students mentioned that the tinkering of his partner to the proposals that he offered was extremely inspiring. He declared that it was beneficial to both of them as mingling each other solutions usually helped them in proposing a valid solution and in developing it to more interesting and unique alternatives

Others mentioned how thinking out loud, talking about ideas to others was important. Listening to insights that emerge from the group rather than trying to push one's own idea, as emphasized by Sawyer (2006), was the spark that lead to numerous alternatives and solutions. For example, while trying to lift the weight on the platform and after nearly losing hope, one of the group members who was meticulously observing the trials yelled "Let us weave the sticks" and this was it (Fig. 13). Another group highlighted how discussion and collaboration has helped them in taking the challenge even further and applying heavier objects to the platform instead of only the bottle and when showed stability and strength; they became more confident and took higher risks and were driven to more complex challenges.

In that sense, collaboration and discussion are assets that significantly helps in generating genuine and new ideas which lies at the heart of any design discipline. Listening, talking, observing and accordingly developing solutions constantly leads to better results. Scientists, designers and professionals in all fields reported that their most innovative ideas and substantial results emerged from collaborations (John-Steiner, 2006).

### *4.2.4. Defer and Postpone Early Judgment*

During those workshops and exercises, students developed a deeper understanding of how early and quick judgement specifically during the generation phase might deprive them of formulating a unique and creative solution. In fact, it is impossible to be curious and judgmental at the same time. They reflected that such an early assessment, especially within a group, that an idea does not work, negatively affected their level of engagement and suppressed their energy, spirit and contribution. In the second workshop, one of the groups arranged the sticks in a peripheral manner trying to lift the given weight and one of them quickly decided that this is impossible and the whole group got trapped, frustrated and lost the momentum for some time unable to propose other alternatives (Fig. 14a). On the contrary, another group reached the same point and they kept trying even if it looks impossible until they were able to lift the bottle using the sticks arranged only in a peripheral manner by placing the bottle horizontally and it worked (Fig. 14 b). Not only did they achieve this alternative, but they were also able to challenge themselves more and more presenting better and more complex alternatives, just because they deferred early judgement and had high tolerance to uncertainty.

Those findings are in accordance with other previous studies. For Puja Khatri & Sumedha Dutta (2018), a stress free or a non-judgmental environment helps students to express their ideas freely and this in turn opens the learning environment to new thoughts and opportunities. Furthermore, in a group work or brainstorming session, success is related to two main principles one of which is deferring judgement (A.F. Osborn, 1963) and allowing the creative current to flow. Inevitably, this is very important in proposing solutions to ill-defined and tangled design problems.

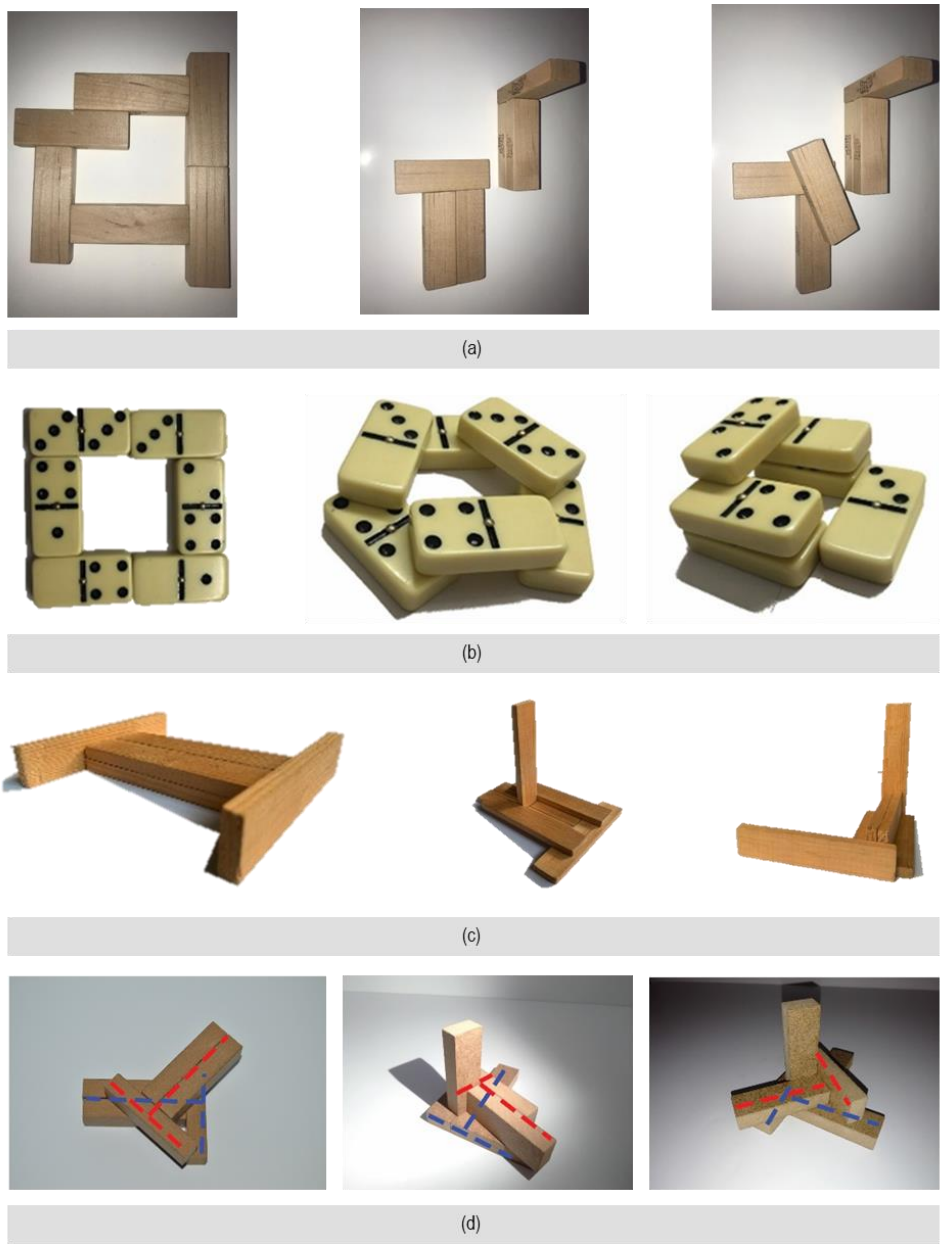



Fig.12. Challenging the conventional self-imposed constrains and assumptions by wondering (a) does it have to be a loop? *(workshop one, problem 1, group 7)*, (b) does it have to be one level? *(workshop one, problem 1, group 9)*, (c) does it have to be symmetrical? *(workshop one, problem 3, group 15)* and (d) can a diagonal relationship help in solving the problem? *(workshop one, problem 4, group 12)*


Fig.13. Collaboration and discussion to lift the weight (a) as one of the members yelled "let us weave the sticks", (b) and they did *(workshop two, problem 1, group B)*

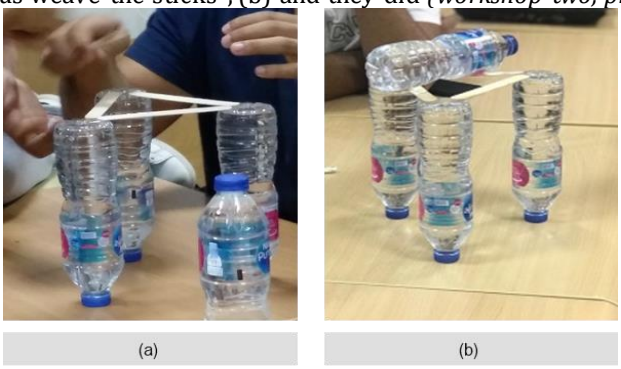



Fig.14. Deferring and postponing judgement as a key issue in creative problem solving (a) quickly judging that it is impossible to lift the weight with sticks arranged only in a peripheral manner *(workshop two, problem 1, group D),* (b) another group lifting the weight using the sticks arranged only in a peripheral manner by placing the bottle horizontally *(workshop two, problem 1, group F)*

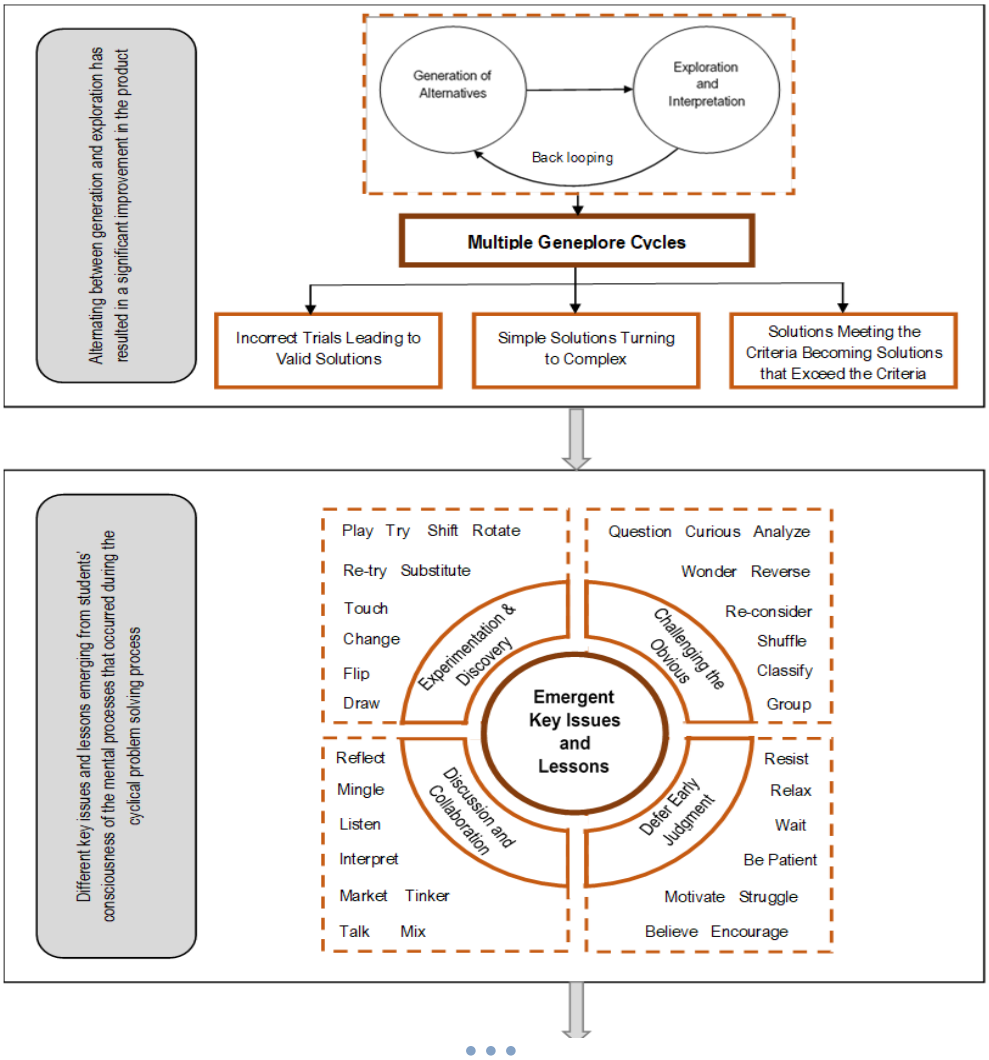
## Conclusion

This paper discussed the importance of addressing creativity, specifically in architectural design education, from a cognitive perspective. It aimed at helping students in discovering their own way of solving problems and identifying its strengths and weaknesses. This stems from a belief that such awareness is considered as a significant step towards the improvement and development of their design thinking skills. The findings of the study, as summarized (Fig. 15)., have emphasized the positive impact of the cyclical behavior in the creative problem solving process and highlighted the different key issues and lessons emerging from students' consciousness of the mental processes that occurred during the problem solving process.

The iterative alternating nature between generation and exploration has resulted in a significant improvement in the product leading to more complex, creative and innovative solutions. Students empirically understood the importance of

experimentation, play and discovery and its role in the creative problem solving process. They experienced how challenging the obvious offered more opportunities and provided new perspectives and insights to the situation. Furthermore, they witnessed and appreciated the important and vital role of collaboration, discussion and deferring judgement in developing, modifying and refining their solutions.

Based on the above analysis and discussion, the awareness and consciousness of those emergent lessons and of the cyclical nature of the creative problem solving process have assisted in developing and nurturing different personality traits. Students' self-confidence, inclination toward risk taking and tolerance for ambiguity have shown improvement and were observed blossoming throughout the process. Such traits are often critical to creativity and innovation in design.



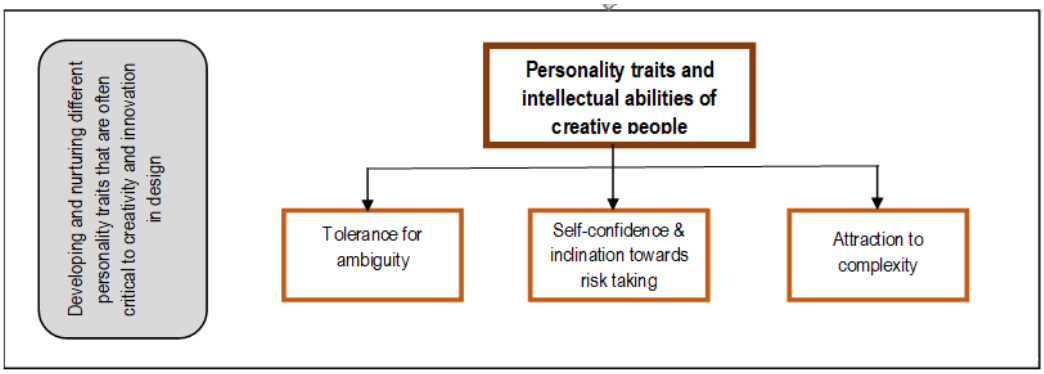



Fig.15. Summary of the core ideas and findings of the study

In conclusion, the findings of the study are expected to encourage conscious design and help students in creatively addressing ill-defined and tangled architectural design problems. Future research could extend the work presented here by exploring further strategies and approaches that couple creativity and architectural design education. More specifically, we need to encourage practical initiatives, in the educational agendas, which work on nurturing and developing the different individual skills and personality traits that often characterize creative and successful designers.

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# An Empirical Analysis of the Relationship among Foreign Direct Investment, Gross Domestic Product, $CO_2$ Emissions, Renewable Energy Contribution in the context of the Environmental Kuznets Curve and Pollution Haven Hypothesis Regarding Turkey

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## Abstract

This study examines the relationships between GDP per capita, $CO_2$ emission, Renewable Energy Contribution (REC) and Foreign Direct Investment (FDI) and evaluates the Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH) for Turkey. The EKC theory says that with increase in income per capita the pollution also increases but in a turning point when nation become richer pollution starts to decrease according to stringency of environmental regulations and implying advanced green technologies due to requirement of nation. In another hand the PHH assume that due to stringency of environmental regulations and high taxes the production become more expensive in developed countries, thus those dirty industries shifts from environmentally stricter developed countries to poor regulated developing countries. The aim of this study to analyze and investigate: which theory (EKC or PHH) does exist in Turkish economy and does FDI has positive impact on sustainable development. The time series datasets (FDI, GDP, CO2 and REC) , those were obtained from World Bank database, which covers the time period 1970-2014 were utilized in employed statistical models as the ADF Unit Root, Philips – Perron, Johansen co-integration, and the Granger Causality tests, to accomplish the empirical part of the paper. Based on the empirical results, it was approved that there wasn`t existence of the EKC theory in Turkish economy. But according to obtained empirical results it was affirmed that there was the presence of the PHH theory in Turkish economy which means the FDI has a negative impact on sustainable development of Turkish economy. Thus, the developed countries with stricter environmental regulations (mostly from Europe) relocate their heavily polluted dirty industries to Turkish economy.

**Keywords:** Foreign Direct Investment, $CO_2$ Emissions, Gross Domestic Product, Renewable Energy Contribution, Environmental Kuznets Curve, Pollution Haven Hypothesis, ADF and Philips-Perron Unit root tests, Johansen Co-integration test, Granger Causality test

## 1. Introduction

The protection of the World from environmental degradations has become one of the most important missions of nations. The one of the urgent cases among pollution is a carbon dioxide (CO2) emission which comes from human activities such as: cement production, deforestation as well as the burning of fossil fuels like coal, oil and natural gas. The first time this urgent issue came up on the agenda by United Nations Framework Convention on Climate Change in 1992, the international community has entrusted its secretariat with a growing responsibility to strengthen the global response to climate change and close the gap between ambition and achievement ("UN Climate Change Annual Report 2017 Website Now Live | UNFCCC," n.d.). In 1997, the world`s nations recognized the significance of environmental pollution with the increasing level of CO2 emissions, Parties to the Convention adopted the Kyoto Protocol, which created binding emission reduction targets for developed countries. During its first commitment period, 2008– 2012, 36 industrialized countries and the European Union pledged to reduce their emissions by an average of just over five per cent compared with 1990 levels ("UN Climate Change Annual Report 2017 Website Now Live | UNFCCC," n.d.). In Paris in December 2015, countries bound oneself to limit the rise of global average temperature to well below 2 °C and as close as possible to 1.5 °C above pre-industrial levels and to prevent dangerous human-induced climate change with signing the latest and ambitious Paris Agreement ("UN Climate Change Annual Report 2017 Website Now Live | UNFCCC," n.d.).

Furthermore, with globalization processes, liberalization and free movement of capital made foreign direct investment inflows to be rapidly intensified in 1980-1990s in the world arena. There is both a positive and negative impact of FDI for the host country. As a positive effect of FDI on the host country it can be considered the flow of finance, capital, new management and new advanced technology. Thus, they can encourage the country to replace old technologies with modern environmentally friendly technologies. But the environmental pollutions can also be raised through FDI (capital intensive dirty industries). We can take in consideration 2 hypotheses in this case, Environmental Kuznets Curve (EKC) and Pollution Haven Hypothesis (PHH). The EKC theory says that, with increase in income per capita pollution, also, increases but in a turning point when nation become rich they will require clean environment and the government will strengthen environmental regulations and due to this issue ( to avoid high taxes) the companies will apply clean technologies for production. The PHH says that because of stringent environmental regulations and high taxes, the developed countries transfer their heavy-polluting industries to lax environmental regulated developing countries.

The main purpose of this study reconsider the relationship between Foreign Direct Investments, CO2 emissions, Renewable Energy Contribution and Gross Domestic Product. Additionally, to investigate which theory (EKC or PHH) exists in economy of Turkey. The content of paper will be structured as follows: In section 2 literature reviews will be expounded, in section 3 data description will be shown, in section 4 methodology

will be disclosed, in section 5 empirical results from employed statistical analysis will be expounded, in section 6 conclusion will be described and finally in section 7 references will be shown.

## 2. Literature review

### *2.1 Theoretical studies*

#### *2.1.1 Environmental Kuznets Curve hypothesis (EKC) and FDI linkage*

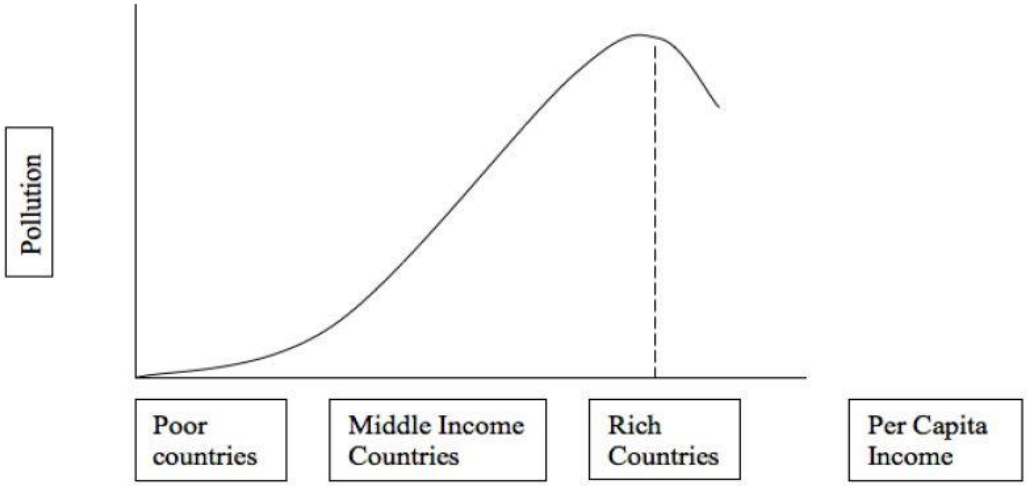
The Environmental Kuznets U-shaped Curve was invented by Simon Kuznets in 1955 (later was awarded with Nobel Prize in 1971), in which the relationship between growth in per capita income and environmental degradation illustrated by U-shaped Curve. Therefore, EKC hypothesis was introduced and became more popular with Grossman and Krueger`s publications (G. Grossman & Krueger, 1991; G. M. Grossman & Krueger, 1995) and World Bank Report (Shafik & Bandyopadhyay, 1992). According to EKC theory ( opposite to PHH) the pollution is increased in poor nations with economic growth and is decreased when nation reaches higher income level, based on the relationship between income level and environmental degradation takes the inverted U-shape (Kerekes, Marjainé Szerényi, & Kocsis, 2018). This happens because developing (poor) countries don`t have enough advanced technologies or capital for implementing such kind of technologies for pollution abatement versus developed (rich) countries have enough level of technologies and capital for implementing these technologies (K. V. Murthy & Gambhir, 2018) (See Graph 1). Therefore, Foreign Direct Investment flows from developed countries which bear to uphold strict environmental standards, because of stringent regulations. Those companies can use energy-saving production which the developed countries transfer from home countries to invested country to influence for energy-efficiency in the host country. Thus, in the context of above mentioned claims, the Foreign Direct Investment can transfer new type of advanced environmentally friendly technologies and human capital, based on these the FDI can have positive effect on environmental performance and raise environmental standards through the transfer of cleaner technology and better management practices, which in turn leads to the incline in the usage of renewable energy and decreasing of CO2 emissions (Marton & Hagert, 2017).

#### *2.1.2 Pollution Haven Hypothesis (PHH) and FDI linkage*

The Pollution Haven Hypothesis implies that polluting industries will relocate to environmentally poorly regulated administrations. The PHH was first postulated against of EKC theory by Copeland and Taylor (Copeland & Taylor, 1994) in the context of North-South trade under NAFTA. It was the first paper that links the environmental regulation stringency and trade patterns with the level of pollution in a country (Gill, Viswanathan, & Karim, 2018). The PHH argues that, the developed countries transfer the pollution intensive industries to less developed countries with unrestricted environmental regulations to avoid huge amount of taxes. Thus, if we will apply EKC U-curve for PHH

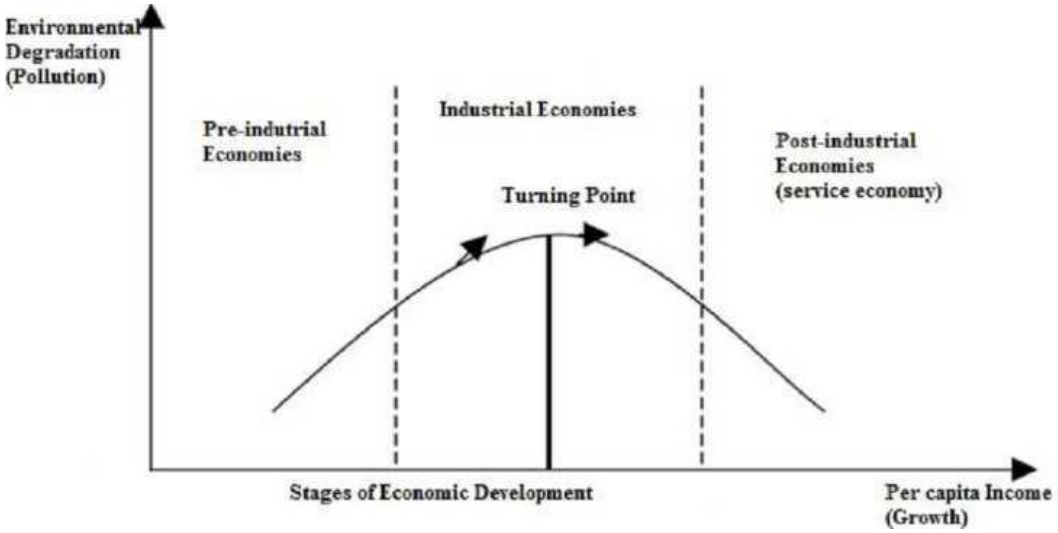
we can see that till the developing country will reach to developed ones, the pollution will be increased parallel with economic growth, but after in a certain amount of costs of pollution the developed countries will shift pollution intensive industries to the developing countries with lax environment standards (See Graph 2). Afterwards developing countries will see increase in economic growth but parallel increase in pollution due to pollution intensive industries which were transferred from developed countries (Levinson & Taylor, 2008). The countries that apparent to become pollution havens are capital intensive, thus will attract MNCs (Foreign Direct Investment) with capital-intensive industries. In the developing countries (host countries) capital is cheaper (capital intensive industries) therefore, by definition these kind of capital is more pollution intensive. Thus, it can affect negatively in the usage of renewable energy and increase of CO2 emissions (Marton & Hagert, 2017).

**Graph 1: Environmental Kuznets Curve**




Source: **EKC** (K. B. Murthy & Bhasin, 2016)

**Graph 2: Illustrating PHH in EKC Curve (A development- environment relationship)**




Source: (Panayotou, n.d.)

### *2.2 Empirical studies*

The relationship between GDP, FDI and Environmental degradation has been the subject of intense research during the last decades. The empirical studies gave the various results due to analyzed country, amount of series and applied empirical models. Thus, some of those studies showed the existence of EKC and vice versa in analyzed region. In another hand some of those studies also showed existence of PHH and vice versa in examined country. Additionally, in some research it has been found that FDI has positive relationship with environmental degradation and vice versa. For instance, (Hitam & Borhan, 2012), analyzed the Gross Domestic Product (GDP) growth and the environmental degradation for the time period 1965 – 2010 in Malaysia. The relationship between foreign direct investment and environmental degradation has been examined by applying the non-linear model. The results indicated that environmental Kuznets curve existed and foreign direct investment increased environmental degradation. (Khandker, Amin, & Khan, 2018) explored the relationship between FDI and renewable energy consumption from 1980-2015 in the context of Bangladesh. The Johansen`s co-integration test, Granger Causality test, VECM and Cusum test were applied to analyze series. The Johansen's co-integration test confirms that variables are co-integrated in the long run and Granger causality test reveals that there is bidirectional causality between those variables of interest. Through Vector Error Correction Model (VECM), they found no causality between the variables in the short run. The CUSUM test results show that variables were stable. According to results Policies regarding attracting more FDI should be considered to increase the investment

in Renewable energy sector. In the another hand, (Aslanidis & Iranzo, 2009), examined the relationship between growth in per capita income and environmental degradation from 1971-1997. The smooth transition regression (STR) model has been applied for empirical part. The results supported EKC hypothesis. (Jbara, n.d.), examined whether to find evidence that these changes over time are consistent with the PHH or EKC for a three different year 1990, 1995, 2000 in 36 countries. The linear regression model and descriptive statistics were utilized for empirical part. According to the results, there was little evidence to suggest that an EKC existed. There was no evidence to support the PHH. (Cole, 2004), examined the extent to which the EKC inverted U relationship can be explained by trade and specifically the migration or displacement of 'dirty' industries from the developed regions to the developing regions (the pollution haven hypothesis (PHH)). According to results the PHH was existed. (Naz et al., 2019), examined the relationship between renewable energy consumption (REC), foreign direct investment (FDI) inflows, economic growth, and their resulting impact on CO2 emissions for the time period 1975-2016 in Pakistan. The results show that economic growth and FDI inflows both increased CO2 emissions, while REC substantially decreased CO2 emissions during the studied time period. The results do not support the inverted U-shaped Environmental Kuznets Curve (EKC) hypothesis for per capita income (and FDI inflows) and per capita CO2 emissions in a country. The results supported 'pollution haven hypotheses where FDI inflows damage the natural flora of the country. (Leitão, 2014) examined the correlation between economic growth, carbon dioxide emissions, renewable energy and globalization for the period 1970-2010, using time series (OLS, GMM, unit root test, VEC model, and Granger causality) in Portuguese economy. OLS estimator and GMM model demonstrated that carbon dioxide emissions and renewable energy are positively correlated with economic growth. The econometric models also show that the overall index of globalization had a positive effect on growth. The Granger causality reported a unidirectional causality between renewable energy and economic growth. (Balibey, 2015) examined the causal relationships between economic growth, carbon dioxide emission and foreign direct investment (FDI) and evaluates the Environmental Kuznets Curve (EKC) hypothesis for Turkey in 1974-2011. The causality relationships investigated by using the Johansen Co-integration test, The Granger Causality Test, Impulse-Response and Variance Decomposition Analysis of vector autoregression model (VAR) model. The causality relationships displayed that FDI (LFDI) and economic growth (LGDP) had a significant effect on carbon dioxide emissions (LCO2 ). Moreover, impulse-response functions and variance-decompositions of VAR model supported these relationships among LGDP, LCO2 and LFDI. The study investigated the validity of the EKC hypothesis in Turkey for the period 1974-2011 by using regression model approach for the various EKC model forms such as linear, quadratic, and cubic. Consequently, economic growth leaded to degradation of environment and depletion of natural resources. (Pazienza, 2015) examined the relationship between Foreign Direct Investment (FDI) and the environment from 1981-2005 by using panel data analysis. The result of the analysis showed the existence of

negative relationships characterizing the technique, scale and cumulative effects of FDI on CO2. (Linh & Lin, 2014) examined the dynamic relationships between CO2 emissions, energy consumption, FDI and economic growth for Vietnam in the period 1980-2010 based on Environmental Kuznets Curve (EKC) approach. The empirical results obtained from co-integration, and Granger causality tests didn`t supported the EKC theory in Vietnam. However, the co-integration and Granger causality test results indicate a dynamic relationship among CO2 emissions, energy consumption, FDI and economic growth. The short-run bidirectional relationship between Vietnam's income and FDI inflows implied that the increase in Vietnam's income would attract more capital from overseas. (Mert & Bölük, 2016) examined the impact of foreign direct investment (FDI) and the potential of renewable energy consumption on carbon dioxide (CO2) emissions in 21 Kyoto countries. Panel causality tests showed that there were significant long-run causalities from the variables to carbon emissions, renewable energy consumption, and fossil fuel energy consumption and inflow foreign direct investments. The results of their model supported the pollution haloes hypothesis which stated that FDI brought clean technology and improved the environmental standards. However, an inverted U-shaped relationship (EKC) was not supported by the estimated model for the 21 Kyoto countries. Another important finding was that renewable energy consumption decreased carbon emissions.

## 3. Data Description

This investigation considers the secondary time series dataset, which was obtained from the World Bank Database[4] for the period span from 1970 to 2014. All variables were converted into logarithms namely LnFDI, LnGDP, LnCO2 and LnREC. The Eviws-8 has been used for empirical part of paper. These four variables were utilized in the model:

FDI – Foreign direct investment: Inward and outward flows and stock, annual (current US$)

GDP – GDP per capita (US$)

CO2 – Carbon dioxide emissions (kt) are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced

REC - Renewable Energy (toe) contribution of renewables to total primary energy supply (TPES)

## 4. Methodology

### *4.1 Augmented Dickey-Fuller Unit Root Test*

The Augmented Dickey-Fuller test was developed by David Dickey and Wayne Fuller, American statisticians, in 1979. The Dickey-Fuller test is used to determine whether a

[4]World Bank Database
https://data.worldbank.org/country/turkey

unit root, a feature that can cause issues in statistical inference, is present in an autoregressive model. [5] ADF test equation is[6] (1):

$$yt=c+\delta t+\phi y_{t-1}+\beta 1\Delta y_{t-1}+\ldots+\beta p\Delta y_{t-p}+\varepsilon t \ldots\ldots\ldots(1)$$

Where

Δ is the differencing operator, such that $\Delta yt=yt-yt-1$.

The number of lagged difference terms, $p$, is user specified.

$\varepsilon t$ is a mean zero innovation process.

The null hypothesis of a unit root is

H0: $\phi$ =1.

Under the alternative hypothesis, $\phi$ <1.

Variants of the model allow for different growth characteristics. The model with $\delta = 0$ has no trend component, and the model with $c = 0$ and $\delta = 0$ has no drift or trend. The test that fails to reject the null hypothesis, fails to reject the possibility of a unit root.

To estimate the significance of the coefficients in focus, the modified T (Student)-statistic (known as Dickey-Fuller statistic) is computed and compared with the relevant critical value: if the test statistic is less than the critical value then the null hypothesis is rejected. Each version of the test has its own critical value which depends on the size of the sample[7].

### *4.2 Philips-Perron Unit Root Test*

The Phillips-Perron (PP) unit root test was developed by statisticians, Peter C.B. Phillips and Pierre Perron, in1988. Though the PP unit root test is similar to the ADF test, the primary difference is in how the tests each manage serial correlation. Where the PP test ignores any serial correlation, the ADF uses a parametric autoregression to approximate the structure of errors.[8] The mathematical equation of test is[9] (4)

$$yt = c + \delta t + a\, y_{t-1} + e(t) \ldots\ldots(4)$$

Where $e(t)$ is the innovations process.

[5] ThoughtCo, The Augmented Dickey-Fuller Test
https://www.thoughtco.com/the-augmented-dickey-fuller-test-1145985
[6] MathWorks, The Augmented Dickey-Fuller Test
https://www.mathworks.com/help/econ/adftest.html?s_tid=doc_ta
[7] RTMath, Mathematics experts in quantitative finance
https://rtmath.net/help/html/93a7b7b9-e3c3-4f19-8a57-49c3938d607d.htm
[8] ThoughtCo, The Augmented Dickey-Fuller Test
https://www.thoughtco.com/the-augmented-dickey-fuller-test-1145985
[9] MathWorks, Phillips-Perron test for one unit root
https://www.mathworks.com/help/econ/pptest.html

The test assesses the null hypothesis under the model variant appropriate for series with different growth characteristics ($c = 0$ or $\delta = 0$). To estimate the significance of the coefficients in focus, the modified T (Student)-statistic (known as Phillips-Perron statistic) is computed and compared with the relevant critical value: if the test statistic is less than the critical value then the null hypothesis is rejected. Each version of the test has its own critical value which depends on the size of the sample.

### *4.3 Johansen Co-integration test*

The Johansen co-integration test was developed by Danish statistician, Soren Johansen, in 1991. It is a statistical model for testing co-integration between several series those are integrated in order $I(1)$ at 1st difference through trace and eigenvalue tests. The mathematical equation of test is[10] (5):

$$y_t = \mu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$H_0$= there is no co-integration between analyzed series.

$H_1$= there is at most 1 co-integration between analyzed series.

Null hypothesis or alternative hypothesis will be accepted if p-value > 0.05.

### *4.4 Granger Causality Test*

The Granger causality test was developed by British statistician, Sir Clive William John Granger in 1969. It is a statistical concept of causality that is based on prediction. According to Granger causality, a variable X is causal to variable Y if X is the cause of Y *or* Y is the cause of X[11]. The mathematical equation of test is (6):

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \ldots + \alpha_m y_{t-m} + \text{error}_t \ldots\ldots\ldots (6)$$

$H_0$= X doesn`t Granger Cause Y and Y doesn`t Granger Cause X.

Null hypothesizes will be accepted if p-values is more than 0.05.

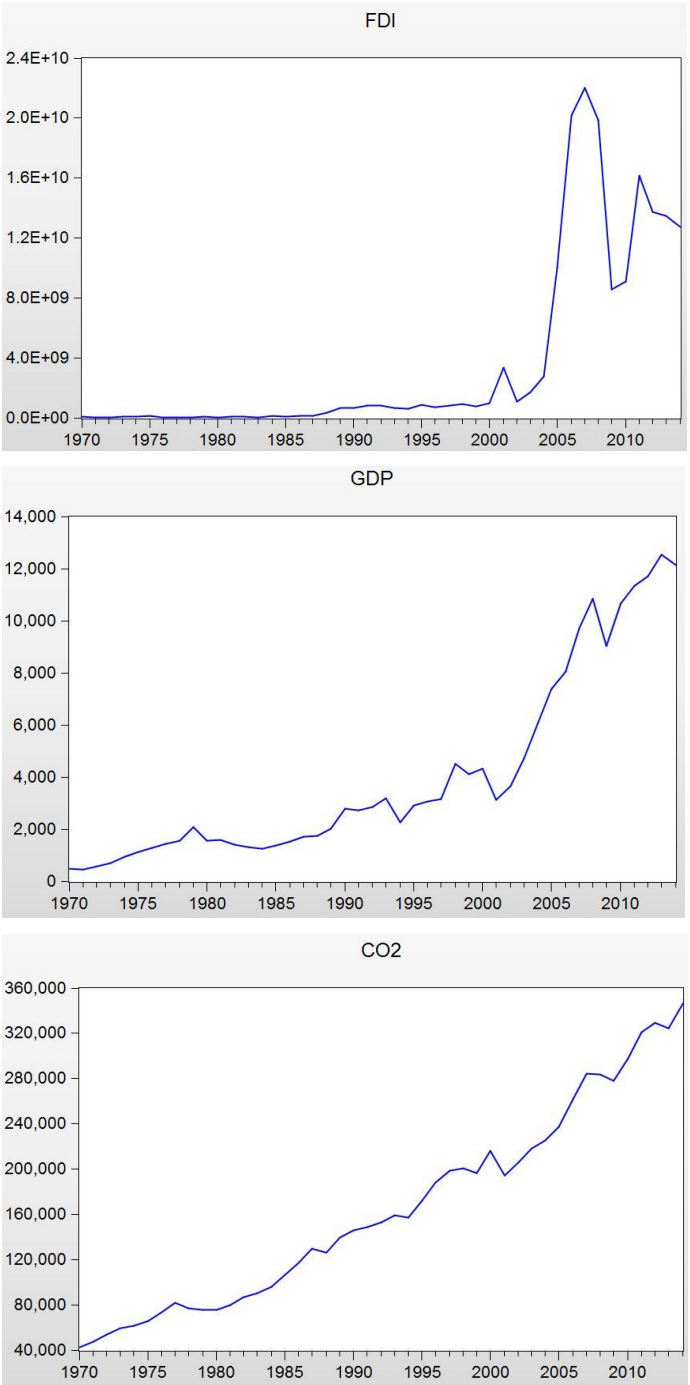
## 5. Empirical Results

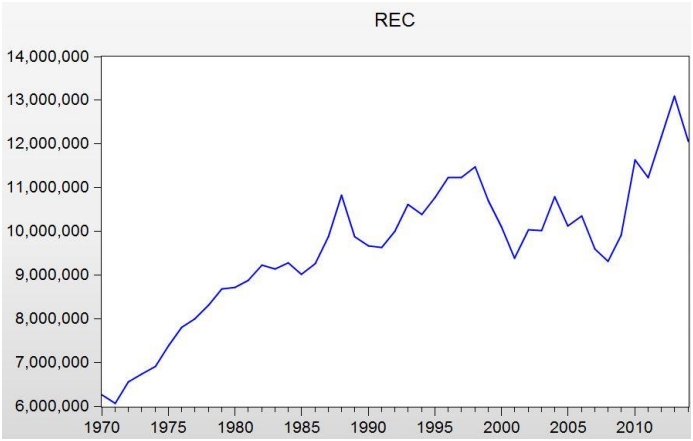
The time series plots for FDI, GDP, CO2 and REC were illustrated in Figure 1 for checking stationary of time series.

[10] IMF - International Monetary Fund, Testing for Co-integration Using the Johansen Methodology when Variables are Near-Integrated https://www.imf.org/external/pubs/ft/wp/2007/wp07141.pdf

[11] Statistics How To, Granger Causality Test https://www.statisticshowto.datasciencecentral.com/

**Figure 1: Time Series plots for FDI, GDP, CO2 and REC**






Source: Author`s own invention based on World Bank Database (E-views 8)

According to graphs it has been seen that all series are non-stationary. Furthermore, the Augmented Dickey-Fuller and Phillips-Perron Unit Root Tests have been applied to determine the stationary of time series.

### *5.1 Augmented Dickey-Fuller Unit Root Test*

As the pre-condition of Johansen co-integration test proposes, selected time-series must be non-stationary at a level and stationary at the 1st difference. Thus, the ADF test individually has been performed on the variables. According to the result of ADF test, the null hypothesis that series has a unit root at levels should be accepted, because T-statistics are less than critical values at 1% and 5% level of significance and P-values of variables are more than 0.05. Thus, after taking the first difference, the series became stationary according to these outputs: T-statistics more than critical values at 5% level of significance and P-values less than 0.05. Based on results, the null hypothesizes that series have unit root at 1st difference should be rejected. Thus, ADF results showed that the observed series appeared to be integrated of order one (I (1)) (See Table 1).

**Table1: Augmented Dickey Fuller unit root test results**

| Null Hypothesis: (LnCO2) has a unit root | | | | | |
|---|---|---|---|---|---|
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnCO2 at level | -1.475990 | 5% | -2.931404 | 0.5361 | Non-stationary |
| Null Hypothesis: (DLnCO2) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnCO2 at 1st difference: | -5.517142 | 5% | -2.933158 | 0.0000 | Stationary |
| Null Hypothesis: (LnGDP) has a unit root | | | | | |

| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
|---|---|---|---|---|---|
| LnGDP at level: | -1.294479 | 5% | -2.931404 | 0.6237 | Non-stationary |
| Null Hypothesis: (DLnGDP) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnGDP at 1st difference: | -3.962755 | 5% | -2.933158 | 0.0037 | Stationary |
| Null Hypothesis: (LnREC) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnREC at level: | -2.484286 | 5% | -2.931404 | 0.1262 | Non-stationary |
| Null Hypothesis: (DLnREC) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnREC at 1st difference: | -4.464795 | 5% | -2.933158 | 0.0009 | Stationary |
| Null Hypothesis: (LnFDI) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnFDI at level: | -0.439081 | 5% | -2.931404 | 0.8930 | Non-stationary |
| Null Hypothesis: (DLnFDI) has a unit root | | | | | |
| Variables | ADF Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnFDI at 1st difference: | -5.518338 | 5% | -2.933158 | 0.0000 | Stationary |

Source: Author`s own calculations

### *5.2 Philips-Perron Unit Root Test*

Additionally, Philips-Perron Unit Root Test was performed for checking stationary level of series. According to the result of PP test, the null hypothesis that series has a unit root at levels should be accepted, because T-statistics are less than critical values at 1% and 5% level of significance and P-values of variables are more than 0.05. Thus, after taking the first difference, the series became stationary according to these outputs: T-statistics more than critical values at 5% level of significance and P-values less than 0.05. Based on results, the null hypothesizes that series have unit root at 1st difference should be rejected. Thus, PP results showed that the observed series appeared to be integrated of order one (I (1)) (See Table 2).

**Table 2: Philips – Perron Unit Root Test results**

| Null Hypothesis: (LnCO2) has a unit root | | | | | |
|---|---|---|---|---|---|
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnCO2 at level LnCO2 | -1.984542 | 5% | -2.929734 | 0.2923 | Non-stationary |
| Null Hypothesis: (DLnCO2) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnCO2 at 1st difference: | -6.089665 | 5% | -2.931404 | 0.0000 | Stationary |
| Null Hypothesis: (LnGDP) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnGDP at level: | -0.991199 | 5% | -2.929734 | 0.7483 | Non-stationary |
| Null Hypothesis: (DLnGDP) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnGDP at 1st difference: | -6.833714 | 5% | -2.931404 | 0.0000 | Stationary |
| Null Hypothesis: (LnREC) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnREC at level: | -2.050739 | 5% | -2.929734 | 0.2650 | Non-stationary |
| Null Hypothesis: (DLnREC) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnREC at 1st difference: | -6.465150 | 5% | -2.931404 | 0.0000 | Stationary |
| Null Hypothesis: (LnFDI) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnFDI at level: | -0.452175 | 5% | -2.929734 | 0.8907 | Non-stationary |
| Null Hypothesis: (DLnFDI) has a unit root | | | | | |
| Variables | PP Test Statistic | Level | Critical values | Prob* | Conclusion |
| LnFDI at 1st difference: | -10.69451 | 5% | -2.931404 | 0.0000 | Stationary |

Source: Author`s own calculations

### *5.3 Johansen Co-integration Test*

Based on the ADF unit root test our series are integrated of the same order, I(1) which means the Johansen co-integration test has been allowed to perform. Johansen co-integration test has been employed for LnCO2 and LnGDP to analyze the long-run relationship between these series. According to the obtained Johansen co-integration test results, those based on trace test and maximum eigenvalue test (p-values in both tests = 0.5472 and 0.7976>0.05), the null hypothesis that there is no co-integration between LnCO2 and LnGDP has been accepted. And the null hypothesis that there is at most 1 co-integration between analyzed series is rejected. It has been confirmed that there is no co-integration between analyzed series (See Table 3).

**Table 3: Johansen Co-integration test for LnCO2 and LnGDP**

| Johansen Co-integration test: Sample (adjusted): 1972-2014, Included obs.: 43, Series: LnCO2, LnGDP, Lags interval (in first differences):1 to 1. | | | | |
|---|---|---|---|---|
| Unrestricted Co-integration Rank Test (Trace) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.115322 | 7.263637 | 15.49471 | 0.5472 |
| At most 1 | 0.045331 | 1.994801 | 3.841466 | 0.1578 |
| Unrestricted Co-integration Rank Test (Maximum Eigenvalue) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.115322 | 5.268836 | 14.26460 | 0.7076 |
| At most 1 | 0.045331 | 1.994801 | 3.841466 | 0.1578 |

Source: Author`s own calculations

The Johansen co-integration test was employed for the next step for LnREC and LnGDP to analyze the long-run relationship between them. According to the obtained Johansen co-integration test results, those based on trace test and maximum eigenvalue test(p-values in both tests = 0.1806 and 0.1793>0.05) the null hypothesis is that there is no co-integration between LnREC and LnGDP, has been accepted. And the null hypothesis that there is at most 1 co-integration between analyzed series is rejected. It has been confirmed that there is no co-integration between analyzed series (See Table 4).

**Table 4: Johansen Co-integration test for LnREC and LnGDP**

| Johansen Co-integration test: Sample (adjusted): 1972-2014, Included obs.: 43, Series: LnREC, LnGDP, Lags interval (in first differences):1 to 1. | | | | |
|---|---|---|---|---|
| Unrestricted Co-integration Rank Test (Trace) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.217252 | 11.53565 | 15.49471 | 0.1806 |
| At most 1 | 0.023056 | 1.003023 | 3.841466 | 0.3166 |
| Unrestricted Co-integration Rank Test (Maximum Eigenvalue) | | | | |

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
|---|---|---|---|---|
| None* | 0.217252 | 10.53263 | 14.26460 | 0.1793 |
| At most 1 | 0.023056 | 1.003023 | 3.841466 | 0.3166 |

Source: Author`s own calculations

The Johansen co-integration test was employed for the further analyzing for LnCO2 and LnFDI to analyze the long-run relationship between them. According to the obtained Johansen co-integration test results, those based on trace test and maximum eigenvalue test (p-values in both tests = 0.0023 and 0.0077<0.05) the null hypothesis is that there is no co-integration between LnCO2 and LnFDI, has been rejected. It has been confirmed that there is at most 1 co-integration between analyzed series (p-values in both tests = 0.0740> 0.05) (See Table 5).

**Table 5: Johansen Co-integration test for LnCO2 and LnFDI**

| Johansen Co-integration test: Sample (adjusted): 1972-2014, Included obs.: 43, Series: LnCO2, LnFDI, Lags interval (in first differences):1 to 1. | | | | |
|---|---|---|---|---|
| Unrestricted Co-integration Rank Test (Trace) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.383898 | 29.08865 | 20.26184 | 0.0023 |
| At most 1 | 0.174806 | 8.261897 | 9.164546 | 0.0740 |
| Unrestricted Co-integration Rank Test (Maximum Eigenvalue) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.383898 | 20.82675 | 15.89210 | 0.0077 |
| At most 1 | 0.174806 | 8.261897 | 9.164546 | 0.0740 |

Source: Author`s own calculations

The Johansen co-integration test was employed for the next step for LnREC and LnFDI to analyze the long-run relationship between them. According to the obtained Johansen co-integration test results, those based on trace test and maximum eigenvalue test (p-values in both tests = 0.2981 and 0.2940>0.05) the null hypothesis is that there is no co-integration between LnREC and LnFDI, has been accepted. And the null hypothesis that there is at most 1 co-integration between analyzed series is rejected. It has been confirmed that there is no co-integration between analyzed series (See Table 6).

**Table 6: Johansen Co-integration test for LnREC and LnFDI**

| Johansen Co-integration test: Sample (adjusted): 1972-2014, Included obs.: 43, Series: LnREC, LnFDI, Lags interval (in first differences):1 to 1. | | | | |
|---|---|---|---|---|
| Unrestricted Co-integration Rank Test (Trace) | | | | |
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.187088 | 9.779805 | 15.49471 | 0.2981 |
| At most 1 | 0.020100 | 0.873119 | 3.841466 | 0.3501 |

| Unrestricted Co-integration Rank Test (Maximum Eigenvalue) | | | | |
|---|---|---|---|---|
| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob. |
| None* | 0.187088 | 8.906686 | 14.26460 | 0.2940 |
| At most 1 | 0.020100 | 0.873119 | 3.841466 | 0.3501 |

Source: Author`s own calculations

### *5.4 Granger Causality test*

In the next step the causal relationship will be checked between LnCO2 and LnGDP.

The null hypothesizes of the test:

$H_0$: LnGDP does not Granger Cause LnCO2, and

$H_0$: LnCO2 does not Granger Cause LnGDP

Null hypothesis will be rejected if the probability value is less than 0.05%.

**Table 7: The Granger Causality Test Results for LnCO2 and LnGDP**

| Pairwise Granger causality test, Lags 2, Sample 1970-2014 | | |
|---|---|---|
| Null Hypothesis | F-statistic | Prob. |
| LnGDP does not Granger Cause LnCO2 | 1.14038 | 0.3304 |
| LnCO2 does not Granger Cause LnGDP | 1.87068 | 0.1679 |

Source: Author`s own calculations

According to the obtained results, the null hypothesis of no causal relationship from LnGDP to LnCO2 should be accepted (P-value=0.3304>0.05). Also, the second null hypothesis of no causal relationship from LnCO2 to LnGDP should be accepted (P-vlue=0.1679>0.05). Thus, the results of the causality test demonstrated that there is no causal relationship from LnGDP to LnCO2 and vice versa (See Table 6).

The later step is checking the causal relationship between LnREC and LnGDP.

The null hypothesizes of the test:

$H_0$: LnGDP does not Granger Cause LnREC, and

$H_0$: LnREC does not Granger Cause LnGDP

Null hypothesis will be rejected if the probability value is less than 0.05%.

**Table 8: The Granger Causality Test Results for LnREC and LnGDP**

| Pairwise Granger causality test, Lags 2, Sample 1970-2014 | | |
|---|---|---|
| Null Hypothesis | F-statistic | Prob. |
| LnGDP does not Granger Cause LnREC | 2.69157 | 0.0807 |
| LnREC does not Granger Cause LnGDP | 0.20702 | 0.8139 |

Source: Author`s own calculations

According to the obtained results, the null hypothesis of no causal relationship from LnGDP to LnREC should be accepted (P-value=0.0807>0.05). Also, the second null hypothesis of no causal relationship from LnREC to LnGDP should be accepted (P-vlue=0.8139>0.05). Thus, the results of the causality test demonstrated that there is no causal relationship from LnGDP to LnREC and vice versa (See Table 8).

The next step is checking the causal relationship between LnCO2 and LnFDI.

The null hypothesizes of the test:

$H_0$: LnFDI does not Granger Cause LnCO2, and

$H_0$: LnCO2 does not Granger Cause LnFDI

Null hypothesis will be rejected if the probability value is less than 0.05%.

**Table 9: The Granger Causality Test Results for LnCO2 and LnFDI**

| Pairwise Granger causality test, Lags 2, Sample 1970-2014 | | |
|---|---|---|
| Null Hypothesis | F-statistic | Prob. |
| LnFDI does not Granger Cause LnCO2 | 1.86025 | 0.1695 |
| LnCO2 does not Granger Cause LnFDI | 4.17188 | 0.0230 |

Source: Author`s own calculations

According to the obtained results, from Granger causality test, the null hypothesis of no causal relationship from FDI to CO2 should be accepted (P-value=0.9478>0.05). But based on P-value= 0.0230<0.05%, the second null hypothesis of no causal relationship from CO2 to FDI should be rejected. Thus, the results of the causality test demonstrated the unidirectional causal relationship from CO2 to FDI (See Table 9).

The next step is checking the causal relationship between LnREC and LnFDI.

The null hypothesizes of the test:

$H_0$: LnFDI does not Granger Cause LnREC, and

$H_0$: LnREC does not Granger Cause LnFDI

Null hypothesis will be rejected if the probability value is less than 0.05%.

**Table 10: The Granger Causality Test Results for LnREC and LnFDI**

| Pairwise Granger causality test, Lags 2, Sample 1970-2014 | | |
|---|---|---|
| Null Hypothesis | F-statistic | Prob. |
| LnFDI does not Granger Cause LnREC | 1.01164 | 0.3732 |
| LnREC does not Granger Cause LnFDI | 1.61336 | 0.2126 |

Source: Author`s own calculations

According to the obtained results, the null hypothesis of no causal relationship from LnFDI to LnREC should be accepted (P-value=0.3732>0.05). Also, the second null hypothesis of no causal relationship from LnREC to LnGDP should be accepted (P-

vlue=0.2126>0.05). Thus, the results of the causality test demonstrated that there is no causal relationship from LnGDP to LnREC and vice versa (See Table 10).

## Conclusion

According to findings from empirical analysis the results can be summarized as follows. The Johansen co-integration and Causality test results indicate that, there was not co-integration and causality between GDP per capita and CO2 emissions; also there was not co-integration and causality between GDP per capita and REC. As we know from above mentioned information the EKC theory says that environmental degradation increases with increasing of GDP per capita and when nation become richer ( they require healthier life), the government applies strict environmental policies and utilize advanced environmentally technologies to decrease environmental degradation. But empirical results of this paper prove that the EKC theory doesn`t exist in Turkish economy. In another hand the empirical results based on the Johansen and Causality test results shows that there was co-integration and causality between FDI and CO2 emissions; also there was not co-integration and causality between FDI and REC. Based on this results FDI which mostly comes from developed countries (United Kingdom (11.9%), Netherlands (11.6%), United States of America (9.3%), Spain (6.6%), Germany (6.5%), Austria (6.1%), Japan (2%), Switzerland (1.7%), China (1.26%), Others (44.31%)("FDI in Turkey - Invest in Turkey," n.d.) ) applies heavy-polluted industries into Turkish economy. These results indicate the existence of PHH in Turkish economy. Which means, because of stringency of environmental policies the developed countries shift their capital intensive dirty industries to Turkey as a developing country.

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# Simpler Machine Learning Using Spreadsheets: Neural Network Predict

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## Abstract

Machine Learning as a phenomenon has gone viral, with many technologists and software vendors promoting it. However, offered tools remain highly technical and not accessible to those without rigorous training in Computer Science or Business Analytics. It would be more useful if end-users can understand it beyond the sales pitch or blind application, and perhaps, even work from scratch to build simple models without much additional training. With better assimilation and acceptance of this AI methodology as an acquired skill and not just head knowledge, many more may want to invest the intensive effort to learn the required tough mathematics and cryptic programming. Or, after simple trial explorations, be willing to put aside substantial budgets to employ skilled professionals for full-scale business application. With simplicity and accessibility in mind, this paper renders Neural Network, a key machine learning methodology, on the ubiquitous and easily comprehensible spreadsheet without macros or add-ins, employing only elementary operations and if so desired, optionally leveraging on its built-in Solver. We will show that backpropagation can be achieved using the elegant though obscure recursive computation feature, with no need for Solver. We will demonstrate the application of neural network on a familiar problem: early and prior prediction of students' graduation GPA. The paper can be used to form the core content for introducing machine learning to non-technical audiences, particularly those majoring in Business and the Social Sciences.

**Keywords:** machine learning, neural network, business analytics, spreadsheets, education, higher education, experiential learning

## 1. Introduction

Machine Learning is garnering lots of attention recently in academia as well as in the public media and businesses. Many technologists and software vendors are promoting

aspects of Machine Learning, particularly Artificial Neural Network (NN) and Deep Learning. Though NN has been around since the 1950s and is thus not entirely new, its resurgence is largely due to the broad-scale, high-speed, and low cost of computation, wireless communications, and the massive availability of live data arising from the Internet and smartphone usage, relative to earlier days of conception. As a result, billions of dollars of investments by vendors and users alike are going into NN development and application.

The original Coursera Machine Learning (ML) course by Ng (2017) has been immensely popular, with 1.7 million enrollments since the course began in 2012 and many more people continue to take it via Coursera (or watch the lecture recordings through YouTube), to learn the basic concepts and techniques in ML (supervised and unsupervised learning, neural network, support vector machines and clustering), underlying statistical techniques (single and multiple linear and logistic regressions) and mathematics (linear algebra, forward propagation and backpropagation, gradient descent optimization and data parallelization), software tools (Octave), practical project ideas (regularization, validation, development strategies, dimensionality reduction, data normalization and visualization), and application (anomaly detection, recommender systems and image recognition).

As the onerous list of related topics above suggests, this is a highly technical course catered for scientists and engineers, though learners are already spared from R or Python programming languages and associated TensorFlow and other libraries. The inherent knowledge, skills, and tools offered by software vendors remain highly technical and not accessible to people without training in Computer Science or Business Analytics. Machine Learning would only become broadly used if the average business executive, non-technical undergraduate or even high-school student could understand it, sans complex mathematics or vague sales pitch. It would be helpful if learners could simply interact with Machine Learning itself, figuratively and from applied fundamentals, starting with building simple models and not just blind application, as is the common practice of imparting programming and subsequently machine learning skills.

The idea of such a teaching technique rests upon pedagogical processes that inculcate the acquiring of skills through a mediated form of practice, rather than simply through verbal instruction of theoretical constructs. The idea of "learning through doing" has been observed in many early civilizations, largely in the form of the master-apprentice relationship, and has in modern times been distilled to what is known as the Experiential Learning Theory (ELT). Kolb (2015) is one of the proponents of this model, which emphasizes the four cyclical stages of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation; the student should repeat the processes ad infineum in the continuous process of learning. The use of such a model in university teaching has been documented by Leong & Ma (2019), in which case studies have shown the deeper levels of understanding from students who have been exposed

to this process of learning, as compared to the common process of imparting of expert knowledge or opinion. The same model also expounds on the relation of academic disciplines as "crafts", and can be deconstructed into the "object" of the craft, the "objective" or goal, and the "skill" required to manipulate the "object" to the "objective". Interestingly, this also turns out to be a qualitative depiction of what NN and ML achieve.

With better assimilation and acceptance of the NN methodology as an acquired skill and not just head knowledge or a black-box, many more may want to spend the intensive effort to learn the required but tough mathematics and cryptic programming, or, after trial application explorations, be willing to put aside substantial budget to employ skilled people to apply them to challenging settings. As the history of AI applications informs us, particularly in medicine, unless end-users can understand, accept and trust it, all abilities deemed "better than human experts", however well-proven, verified and validated, would come to naught.

Therefore, with simplicity and accessibility in mind, this paper attempts to show how NN, a key machine learning methodology, can be rendered on ubiquitous and more comprehensible off-the-shelf spreadsheet applications, directly without macros or add-ins, employing the SUMPRODUCT function for forward-propagation and, if so desired, optionally leveraging the built-in Solver to do gradient descent to optimize the objective function. We will demonstrate the application of NN using spreadsheets on a problem familiar to most institutes of higher learning: early prediction of students' graduation grade point average (GPA) from a basket of factors.

Our paper's key contribution is to show non-technical users more comprehensively what NN is and how to more simply do it, and refresh upon the efforts of others to promote the use of spreadsheets as a tool for learning and applying basic NN concepts. In particular, the paper's novelty is our use of the elegant, though obscure, recursive computation spreadsheet feature and so do away with the need for Solver. Despite the desired exclusion, Solver's use for NN is still thoroughly explained and demonstrated in the paper as it would be handy to those who cannot fully understand or accept recursive computation. The detailed demonstration seeks to allay users' fears of complex mathematics, technical programming, and the like, and approach the building of a NN system using an applied and practical perspective, in particular the ELT approach.

The rest of the paper is organized as follows: Section 2 contrasts our approach against related efforts by other authors, and Section 3 explains the base model for predicting a continuous dependent (or output) variable from multiple continuous independent (or input) variables. Next, Section 4 shows how backpropagation could be done fairly simply, by exploiting the recursive computation explained prior, and finally, Section 5 summarizes the results. The paper ends with a broad discussion on research motivation and future work, to introduce machine learning to non-technical students, particularly those majoring in Business and the Social Sciences.

## 2. Related Work and Literature Review

This paper is part of a series of efforts over the years by the lead author and collaborators to promote the use of spreadsheets as a viable means for the less mathematically- and technically-inclined, in order to explore realistic business scenarios and resolve them, without use of add-ins or macro programming. Problems addressed to date include multi-server queues (Leong 2007a), and data resampling and Monte-Carlo simulation (Leong 2007b, Leong & Lee 2008). NN spreadsheet models may not be suitable for large-scale application but would suffice for teaching machine learning and for preliminary exploratory analysis with less data, prior to embarking on enterprise-level implementation, by which time would involve project teams with capable data scientists and large amounts of data.

There are multiple practical reasons for using spreadsheets (Leong & Cheong 2008). Briefly, spreadsheets permit people with basic mathematical skills and no programming abilities to perform highly elaborate modeling of business challenges by making algebraic, statistical and probabilistic computations to appear arithmetic. Its interface is simple and highly interactive, plus its ubiquitous presence in offices, led many analysts to consider it as the tool of choice for exploring business opportunities.

With many educators, especially in universities, adopting spreadsheets as their main computing platform to support teaching of business mathematics, statistics, and management science courses, not to mention its common use among students, graduates can now more easily apply spreadsheets for quick data analysis, as well as for understanding approaches to formation of complex solutions. Even people without formal training and only direct experience with spreadsheets can pick up advanced modeling techniques (Leong & Cheong 2008, 2015). Therefore, the primary key advantage of using spreadsheets is that it would allow a wider end-user audience to experience first-hand what machine learning actually is and how applications may be easily constructed and flexibly adapted for use.

There appears to be few academic papers on using spreadsheets to apply machine learning. In fact, Sarkar *et al* (2015) lament the lack of tools accessible to non-experts and offered BrainCel, a visual interface system for performing machine learning in a spreadsheet-like environment to do clustering. BrainCel is user-friendly as a machine learning system but it insulates users from the logical processes. Similarly, Koong, Mcgee & Leong (2010) presented a tutorial software application for imparting NN knowledge to less technically inclined students. These used propriety software and, unlike standard spreadsheets such as Excel, require much training that could go to waste if and when their platforms do not stand the test of time.

Werbos (1988), who pioneered backpropagation in NN and demonstrated its use in a spreadsheet, employed macros to cycle through the iterations so as not to involve avoid having numerous rows to store the weights in each step. Rienzo and Athappilly (2012) shares our enthusiasm in applying spreadsheets to NN but in avoiding macros, could

only work on small problems that required no more than 4 iterations. Semerikov *et. al* (2019) addresses the multi-classification of Iris botanical types using spreadsheets and applied Solver to determine the weights. Kendrick, Mercado, and Amman (2006) in chapter 2 of their textbook applied Solver in their NN spreadsheet to forecast stock prices, calling it a "grey-box" concept.

There are some useful articles by professionals on web forums and blogs that address the use of spreadsheets for machine learning. However, they cover only base level statistical analysis approaches such as Linear Regression and Logistic Regression. For example, Granville (2017) uses complex array functions (i.e., CORREL, COVAR and LINEST). This approach makes the models opaque, as users cannot see how the detailed computations are done. Still others like Roberts (2018) introduced the use of the PyXLL Add-in that embeds Python in Excel to extend the spreadsheet's functionality to take advantage of the Python ecosystem. Smith (2018) adopts a play-learning approach to apply Excel to NN, as a "Skynet" game and Ekman (2019) applies spreadsheet macros to do backpropagation. Finally, more focus should be given to NN applications in business and for this, we refer the reader to the literature review and analysis paper by Wong, Bodnovich, and Selvi (1997).

## 3. Base Model

The basic idea behind machine learning is to be able to understand how a set of independent variables (X1, X2… Xn) relates to a dependent variable (Y). To illustrate, we may let Y, the variable to predicted, be a student's result in an English test, and X1 may be the number of hours the student studied, X2 the hours slept the night prior to the test, and so on. What machine learning aims to achieve in this scenario would be to predict the value of Y, given the X variables' values of a particular student, before the actual test is conducted, through the assignment of weights to each variable and the corresponding mathematical relationship (both of which are computed through the learning process). The choice of X variables is therefore important for proper forming of the relationships between the chosen X variable and the correlation to the Y variable. In a basket of chosen X variables – e.g., students' weight, height, gender, or results in their past English or Math tests – we may also find that there are different weights to each variable, and relationship between the independent and dependent variables; sometimes unexpected, and in varying degrees.

Now if we have access to a set of data from past years' students, we may then be able to find a function (F) to fit the multiple Xs to Y. The output of F(X1… Xn) using the given data, and after the algorithm has been formed, should give a value as close as possible to the actual Y. In Statistics and NN, we use linear functions as follows:

$$YP = F(X1 \ldots Xn) = W0 + W1 * X1 + W2 * X2 + \ldots + Wn * Xn \quad (1)$$

where YP is the predicted value of Y and weights W0, W1, …, Wn are constants to be determined as part of the algorithm. In the single X variable case, W0 is the Y-intercept

and W1 is the slope. As the variables may be quite different in magnitudes from one another, the data need to be normalized and re-scaled -this is assumed done prior to any computation, and detailed discussion is left for later.

The analysis thus far is called "Linear Regression". NN expands on this idea, using concurrent multiple copies of this function (shown schematically in Figure 1). Furthermore, beyond continuous variables, NN also deals with categorical variables. To avoid complex mathematics, we will explain this in practical terms using spreadsheets.

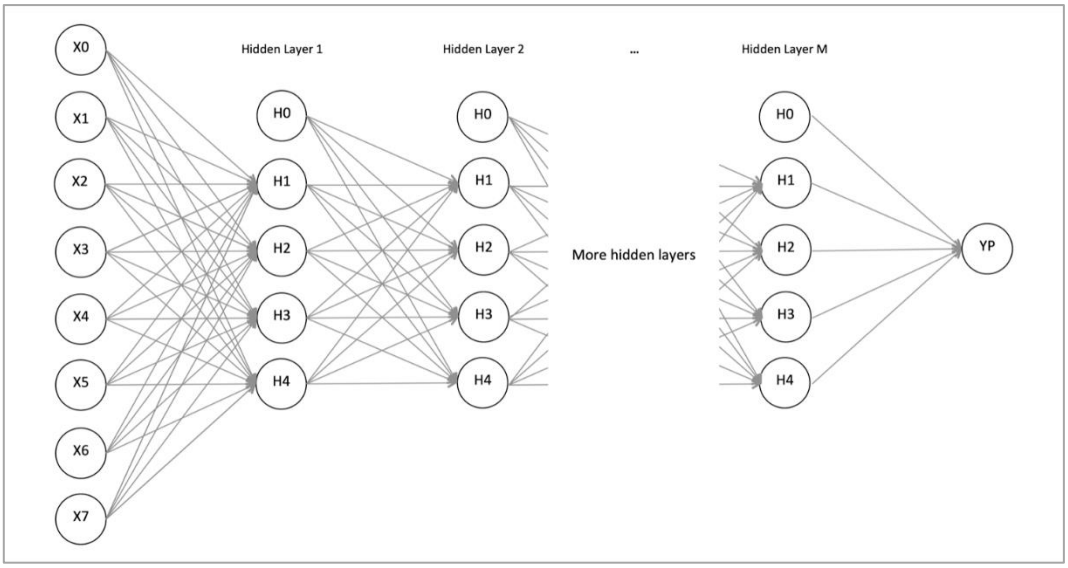


*Figure 1: Neural Network Schematic*

The final function of Y can be thought of simply as a weighted sum (or function) of the various X variables. With the final function, we compute the YP value for each data point and compare it against its Y value. For goodness of fit, it is easiest to use Mean Absolute Error, the average of absolute values of YP minus Y. The W values, initialized usually with random values, are also tuned to improve the fit. The function with weights being improved is thus learning from the data. In NN, this is termed "supervised learning" since there exist Y values in the given data that can be used to compare against the YP values and thereby improve the function. "Unsupervised learning", in which the outcome (Y) value or variable is not known, will not be discussed further in this paper. (Do note that the Computer Science community may use a different nomenclature from mathematicians; notably that variables are referred to as features and formula (1) above as forward propagation.)

We can use spreadsheets to illustrate the process of determining this function of Y respect to X. To do so, we first examine the NN Predict GPA spreadsheet model (see Figure 2). This model tries to predict students' graduation GPA from the grade points of

seven pre-selected courses (indicated in the table header as C01-C07). These courses were specifically chosen because they are taken early in the students' academic programme and their students' grade point values in these courses singly correlate to the GPA better than other level 1 or 2 courses (typically taken in their first two years of a four-year undergraduate course). The data values involved are all continuous and the variables' minimum and maximum possible values are the same, thus well behaved.

**Neural Network Predict** 2-Layer (7-4-1)

GPA from Early Courses' Grade Points — Using Solver

Initialise weights with random values

| Mean Abs Error | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.13 | 0.18 | W1 | 0.99 | 0.52 | 0.60 | -0.11 | 0.28 | 0.30 | 0.23 | 0.69 | 0.11 | 0.27 | 0.05 | -0.01 | 0.11 | W |
| Train | Test | W2 | 0.74 | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.46 | 0.01 | 0.48 | -0.15 | 0.36 | Rand |
| | | W3 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | |
| ReguTerm | | W4 | 1.18 | 0.17 | 0.00 | 0.00 | 0.00 | 0.66 | 0.04 | 0.00 | | | | | | |
| 0.00 | | Rand | 0.40 | -0.23 | 0.31 | 0.36 | -0.01 | 0.49 | -0.19 | -0.27 | | | | | | |

Regu

| 0.01 | | | | C01 | C02 | C03 | C04 | C05 | C06 | C07 | Hidden Layer | | | | | Error | Out |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/N | YP | Y | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | Z0 | Z1 | Z2 | Z3 | Z4 | YP | YP |
| 1 | 3.57 | 3.29 | 1 | 3.5 | 3.0 | 4.0 | 3.0 | 5.0 | 3.5 | 4.5 | 1 | 10.4 | 0.7 | 0.4 | 5.3 | 0.28 | 3.57 |
| 2 | 4.13 | 4.13 | 1 | 4.0 | 5.0 | 4.0 | 4.5 | 4.0 | 5.0 | 5.0 | 1 | 12.7 | 0.7 | 0.4 | 4.8 | 0.00 | 4.13 |
| 3 | 4.35 | 4.58 | 1 | 5.0 | 5.0 | 4.0 | 4.5 | 5.0 | 5.0 | 4.5 | 1 | 13.2 | 0.7 | 0.4 | 5.6 | -0.23 | 4.35 |
| 4 | 3.64 | 3.58 | 1 | 4.0 | 4.0 | 4.5 | 5.0 | 4.0 | 4.0 | 3.5 | 1 | 10.9 | 0.7 | 0.4 | 4.7 | 0.06 | 3.64 |
| 5 | 4.06 | 4.24 | 1 | 4.0 | 5.0 | 4.5 | 4.0 | 4.5 | 5.0 | 4.5 | 1 | 12.3 | 0.7 | 0.4 | 5.1 | -0.18 | 4.06 |

*Figure 2: NN Predict GPA (2-layer; using Solver)*

Cells E5:L5 contain the weights for computing variable Z1 from constant X0 (value 1) and variables X1 to X7. Z1 (in cell N15) is given by the formula:

=SUMPRODUCT($E$5:$L$5, $E15:$L15)
(2)

Similarly, cells E6:L6 contain the weights for computing Z2. Z2 (in cell O15) is given by:

=SUMPRODUCT($E$6:$L$6, $E15:$L15)
(3)

and so on, each time using the weights in the next row. Therefore, variables Z1 to Z4 are weighted sums of X0 to X7; and with X0 equals 1, its associated weight W0 is the bias. These formulas are copied down from row 12 to other rows to cover other input instances.

Incidentally, output variable Z1's formula above would be the same as that for predicted output YP of a 1-layer NN (i.e., with no hidden layers) and only the weights in E5:L5 are pertinent. Now for the 2-layer NN, variables Z0 to Z4 constitute the hidden layer where

Z0 like X0 equals to 1. The second and last layer gives the predicted output variable YP (in cell S15) is computed from Z0 to Z4 (in cells M15:Q15) as follows:

=SUMPRODUCT(M$5:Q$5, M15:Q15) (4)

We reproduce a copy of this YP in cell C15 at the far left of the spreadsheet model, using formula =S15, to facilitate easy comparison with the actual Y in cell D15. And for the same reason, at the far right, cell R15 (with formula = S15−D15) shows the prediction error.

Instead of having numerous SUMPRODUCT formulas in cells N15:Q49, we can alternatively use one array formula {=MMULT(E15:L49,TRANSPOSE(E5:L8))}. This array formula approach is not recommended because array functions MMULT and TRANSPOSE made the model inflexible: difficult to add more training data or modify the NN's structure, say deleting columns to remove weak variables. Further explanations explanations on the use of the $ sign in cell references, and function SUMPRODUCT, and array functions TRANSPOSE and MMULT are included in the Appendix.

To expand the model with more layers, hidden layers can be inserted and SUMPRODUCT formulas applied similarly, by treating each preceding hidden column's Z's as if they are X's. Having many layers and inclusion of more complex structures give rise to what is known as "Deep Learning" in NN. In all NN, the learning comes from progressively adjusting the weights in response to feedback errors, thereby improving predictability. An easy approach to do this is to use Solver: minimize cell B5 by changing E5:L8 and M5:Q5, where the Mean Absolute Error (MAE) objective or loss function in cell B5 is given by array formula:

{=SUM(ABS(R15:R39))/COUNT(R15:R39)} (5a)

where R15:R39 contains the prediction errors for the training data. That is, errors of the test data in rows 40 to 49 are excluded.

Solver's GRG Nonlinear Solving Method used is the vendor-enhanced version of the Generalized Reduced Gradient (GRG2) code developed by Leon Lasdon and Alan Waren. We have started to apply array formulas (not the same as array functions). Though often unfamiliar to casual spreadsheet users, array formulas are simpler than array functions (see Appendix).

Formula (5a) computes the average of the absolute magnitude of errors between the actual and predicted dependent variable values. We have chosen MAE because it gives equal weightage to errors regardless of error size and is thus easier for end-users to understand. The objective function enhanced by adding a regularization term is as follows:

=SUM(ABS(R15:R39))/COUNT(R15:R39)

+ B12*SUM(ABS(F5:L8),ABS(N5:Q5))/COUNT(F5:L8,N5:Q5) (5b)

where cell B12 holds regularization rate and cells F5:L8 and N5:Q5 contain weight values less the bias terms. This rate should be adjusted to influence magnitudes of the weights and thereby moderate over-fitting and bias issues. Formulas for key cells of the completed model are summarized in Figure 3.

| *Documentation* | | |
|---|---|---|
| MAE Obj: Train | B5 | {=SUM(ABS(R15:R39))/COUNT(R15:R39) +$B$10*SUM(ABS(F5:L8),ABS(N5:Q5))/COUNT(F5:L8,N5:Q5)} |
| Test | C5 | {=SUM(ABS(R40:R49))/COUNT(R40:R49) +$B$10*SUM(ABS(F5:L8),ABS(N5:Q5))/COUNT(F5:L8,N5:Q5)} |
| MSE Obj: Train | B5 | {=SUM((R15:R39)^2)/COUNT(R15:R39) + ... |
| Test | C5 | {=SUM((R40:R49)^2)/COUNT(R40:R49)} + ... |
| W1, Wgts for Z1 | E5:L5 | <Input>, initialized with random values |
| W for Output YP | M5:Q5 | <Input>, initialized with random values |
| | | |
| Output Predicted Y | C15 | =S15 |
| Y | D15 | <Input> |
| Input X0, X1-X7 | E15:E49 | 1, <Input> |
| Z0 | M15:M49 | <Input>, 1 |
| Z1 | N15 | =SUMPRODUCT($E$5:$L$5,$E15:$L15) |
| Z2 | O15 | =SUMPRODUCT($E$6:$L$6,$E15:$L15) |
| Z3 | P15 | =SUMPRODUCT($E$7:$L$7,$E15:$L15) |
| Z4 | Q15 | =SUMPRODUCT($E$8:$L$8,$E15:$L15) |
| YP Error | R15 | =S15-D15 |
| YP | S15 | =SUMPRODUCT(M$5:Q$5,M15:Q15) |

Figure 3: Formulas of key cells in the NN Predict GPA

## 4. Results

An illustrative explanation to the model is to treat each Z value as the score given by an expert evaluator, computed by taking a weighted sum of independent variables' values. These expert-specific weights are based on individual evaluator's "subjective judgment". In turn, a weighted sum of the experts' scores can be taken as the score of an expert panel. There can be more than one of such panels, and then in turn, weighted average of panel scores can be taken to give an expert committee's score, and so on. Each time, a hidden layer is added to the NN in an attempt to make it more robust.

Often only a simple NN model with 1 or few hidden layers, with each layer having few variables, is needed. In its simplest, with no hidden layers, the NN model is the same as linear regression. We can put the linear regression model into effect by setting irrelevant X and Z weights (cells E5:L8, M5 and O5:Q5) to 0, and weight of Z1 (cell N5) to 1, after which Solver only needs to change cells E5:L5 to get the local optimal solution for the weights.

In our model, we have split the data into two mutually exclusive sets: the training set and the testing set. As per usual machine learning practice, the training data is used to build the model by calibrating weights, while the testing data (where the weights, obtained from the training data, are held constant) checks how well the model performs. More

clearly, the testing data cannot be involved in tuning the weights. If actual outputs are known, especially soon after prediction rather 4 years later upon student graduation, the weights can be updated continually, as each data point is being introduced, allowing early discovery of prediction errors which may influence future predictions.

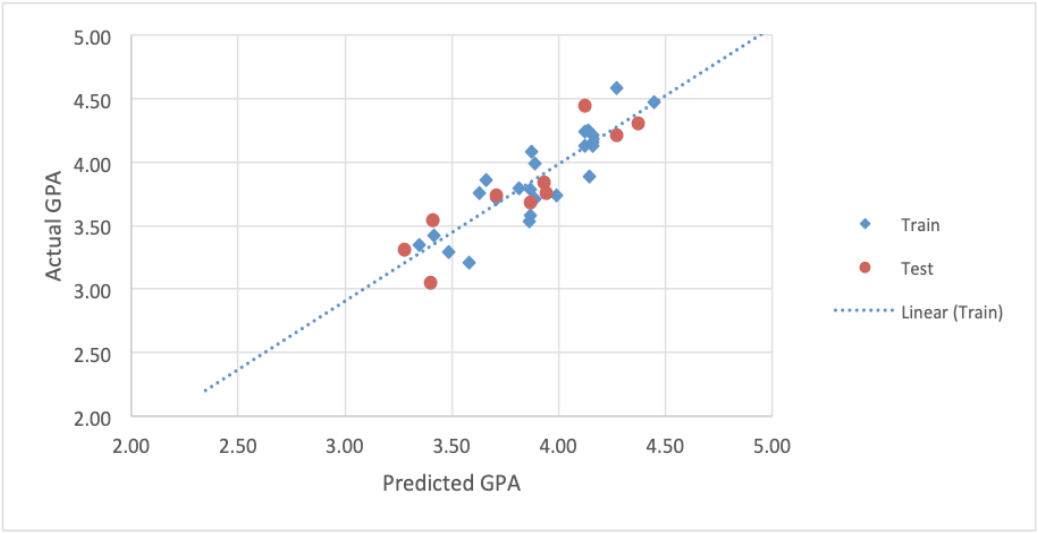


*Figure 4: NN Predict GPA Results (using Early Course Grades)*

The results (Figures 2 and 4) show that the NN model can predict the GPA with high levels of accuracy, with training and testing MAE of 0.13 and 0.18 respectively for the data set. This means that the weights that have been tuned can fit the model to give an average deviation from actual GPAs by 0.13 grade points. When model is applied to data outside the training set, it is expected to do slightly worse and the average deviation is now 0.18 grade points. (i.e. if the model predicts that a student GPA is 4.0, then on the average it is wrong by ±0.18, or that the actual grades are likely in the 3.82 to 4.18 range.)

In an actual problem, the use of pre-admission variables such as demographics (race and gender), education track (academic junior college or technical polytechnics) and other educational priors (high school English or Mathematics results; admission screening test scores). Some variables are binary (e.g., female = 0, male = 1; junior college = 0, polytechnic = 1) while others are categorical, both ordinal and non-ordinal. Non-ordinals would be converted to many binary variables, one for each category, while ordinals may be treated as rounded continuous variables.

When input data are of different magnitudes, pre-processing is required to normalize and rescale them. In this case, we make all variables to be in [0,1] range as follows:

$$\text{Normalized and rescaled } X = (X - Xlow)/(Xhigh - Xlow) \quad (6a)$$

where Xlow and Xhigh are the lowest and highest possible data values respectively of the variable.

If Xlow and Xhigh are infinitely small or large, we use instead:

$$\text{Normalized and rescaled } X = (X - Xmean)/(6 \times Xstdev) + 0.5 \quad (6b)$$

where Xmean and Xstdev are the estimated mean and standard deviation of the population.

In applying the model, caution should be taken here that, for both formulae (6a) and (6b), the Xlow, Xhigh, Xmean and Xstdev should not be changed once decided. They should apply to all data and not dynamically changed as more data is added to the training set. This may pose limitations if the initial training set is not representative of the general range of values, and is therefore a reminder that the data used in both the training and testing sets should firstly be of a significant volume, and secondly, representative of the actual situation.

By adapting the model in Figure 1, replacing the 7 course grade points with 7 other demographic and prior education variables (with the input data normalized and rescaled) and then further pruned the variables to get better results (Figures 5 and 6). As the results show, the model fit now is not as good and is predictably significantly worse. We also eliminated variables found to be weak for prediction (by deleting their weights and excluding them from the "By changing cells" input field in Solver). Overall, it seems pointless to include any of these 7 new variables to the earlier 7 to give a better model. We may then conclude that these seven newer variables are not as strong indicators of the final predicted value as the earlier seven course grade points – at this point, note that we cannot yet say that they have no influence whatsoever, only that they are considerably weaker than the initial seven course grade points.

**Neural Network Predict** 2-Layer (7-4-1)

GPA from Demographics & Edu Priors — Using Solver

Initialise weights with random values

| Mean Abs Error | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 0 | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.16 | 0.32 | W1 | 0.14 | -1.10 | 1.66 | 0.64 | -0.04 | -0.38 | -0.89 | 0.69 | 3.94 | 0.00 | -0.08 | 0.21 | 0.08 | W |
| Train | Test | W2 | 0.02 | 0.17 | -0.01 | -1.84 | 0.58 | 0.37 | 0.02 | 0.00 | -0.22 | 0.19 | 0.32 | -0.06 | 0.36 | Rand |
| | | W3 | 1.68 | -0.52 | 1.07 | 1.44 | -0.30 | 0.05 | -0.53 | 0.08 | | | | | | |
| ReguTerm | | W4 | 2.79 | -3.46 | 1.07 | 0.00 | 0.00 | 0.09 | -0.30 | 1.48 | | | | | | |
| 0.01 | | Rand | 0.41 | 0.03 | -0.09 | 0.43 | -0.28 | 0.37 | 0.23 | -0.36 | | | | | | |

Regu

| 0.01 | | | | Race | Sex | Edu | T1 | T2 | T3 | T4 | Hidden Layer | | | | | Error | Out |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/N | YP | Y | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | Z0 | Z1 | Z2 | Z3 | Z4 | YP | YP |
| 1 | 3.30 | 3.29 | 1 | 1.0 | 0.0 | 1.0 | 6.0 | 5.0 | 8.0 | 3.8 | 1 | -7.0 | 3.8 | -2.9 | 3.0 | 0.01 | 3.30 |
| 2 | 3.92 | 4.13 | 1 | 1.0 | 0.0 | 1.0 | 3.0 | 7.0 | 7.0 | 5.1 | 1 | -5.8 | 2.8 | -1.2 | 5.4 | -0.21 | 3.92 |
| 3 | 3.96 | 4.58 | 1 | 1.0 | 1.0 | 1.0 | 4.0 | 4.0 | 8.0 | 4.7 | 1 | -4.2 | 2.3 | -1.2 | 5.4 | -0.62 | 3.96 |
| 4 | 4.12 | 3.58 | 1 | 0.0 | 0.0 | 1.0 | 3.0 | 4.0 | 8.0 | 4.4 | 1 | -4.9 | 1.6 | -1.4 | 7.3 | 0.54 | 4.12 |
| 5 | 4.47 | 4.24 | 1 | 1.0 | 1.0 | 1.0 | 3.0 | 6.0 | 6.0 | 5.9 | 1 | -2.3 | 2.4 | 0.4 | 7.9 | 0.23 | 4.47 |

*Figure 5: NN Predict GPA (using Demographics and Education priors)*

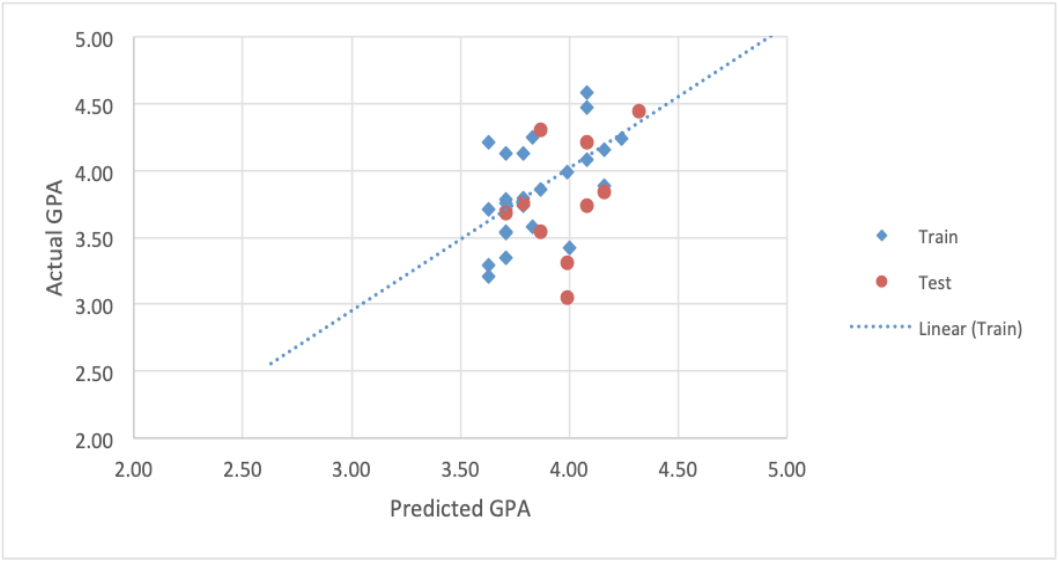


*Figure 6: NN Predict GPA Results (with Demographics and Education Priors)*

## 5. Simpler Approach to NN and ML – An Illustrative Explanation

For learners in business and social science majors, weights can be analogous to prices, predicted output(s) to supply, actual (or required) output(s) to demand, and the

objective function as an overall measure of the extent supply exceeds demand. For the purpose of modelling, prices can initially be set to random values, with a small increase in price (analogous to the learning rate), one at a time, to see how the objective function change, and subsequently increase or decrease that price by the small amount to reduce the objective function value.

With many such prices, we can also at each iteration change all of them simultaneously, although preferably after we have understood how each individual price change impacts the objective function. The algorithm ends when the objective function value cannot be reasonably reduced further with price changes. The price changes at each iteration have to be small, especially if simultaneously changed. Otherwise, the algorithm may not converge and the prices may just be cycling up and down. To get better results and faster convergence, we moderate the price changes to be progressively smaller with each iteration, instead of having constant very small price change sizes. With relatively larger price changes at the beginning, the objective function value would generally drift downwards though cycling up and down slightly. This process can of course be automated using Solver.

Machine learning in general employs a technique called backpropagation to optimize the NN model. Backpropagation computes the partial derivatives for each of the weighted variables, which is the gradient associated to the objective function value change with a small change in a weight. This allows us to adjust weights incrementally using gradient descent, which is identical to the optima obtaining process mentioned, but can be considered a myopic optimization heuristic.

Since MAE is not differentiable, the underlying objective function used is the Mean Square Error (MSE), as given in place formula (5a) by array formula:

{=SUM((R15:R39)^2)/COUNT(R15:R39)}
(7)

where cells R15:R39 contain the prediction errors.

The key criticism of MSE is that by squaring it gives too much emphasis to large errors and thus also difficult for non-technical people to interpret. We therefore retain MAE as the key prediction performance measure.

It can be quite challenging to show the partial derivatives' formulas for NN models with hidden layer(s), and therefore this approach would seem tedious even in a spreadsheet and often involved macro programming. We had therefore used Solver to support end-users who may not want to deal with the complexity and algorithms involved. However, we will next show that by using recursive computation, backpropagation is not as difficult as some make it out to be.

Taking the base NN model in Figure 1, one can render it with no hidden layers (Figure 7). The predicted output variable YP (in cell N15) is now a weighted sum of the independent variable values, given by as in earlier explained formula (2):

=SUMPRODUCT(E$5:L$5, E15:L15) (2)

where E5:L5 contains the current weights. Separately, we set up cells E6:L6 to keep the next iteration's weights. The formula for cell E5 is then:

=IF($D$12="No",RAND(),E6) (8)

where Iteration Start indicator in cell D12 initially contains "No" and thus initialize current weights to random values.

| | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Neural Network Predict** | | | | 1-Layer (7-1) | | | | | | | | |
| 2 | GPA from Early Courses' Grade Points | | | | | | | | | | | Using Iterative Calculation | |
| 3 | | | | | | | | | | | | | |
| 4 | Mean Abs Error | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 5 | 0.14 | 0.16 | W | 0.87 | 0.08 | 0.19 | -0.04 | 0.17 | 0.12 | 0.04 | 0.15 | | |
| 6 | Train | Test | Next W | 0.87 | 0.08 | 0.19 | -0.04 | 0.17 | 0.12 | 0.04 | 0.15 | | |
| 7 | | | | | | | | | | | | | |
| 8 | ReguTerm | | | | | | | | | | | | |
| 9 | 0.00 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 11 | Regu | Learn | Start | Select "Yes" to run | | | | | | | | | |
| 12 | 0.01 | 1.E-03 | Yes | | C01 | C02 | C03 | C04 | C05 | C06 | C07 | Error | Out |
| 14 | S/N | YP | Y | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | YP | YP |
| 15 | 1 | 3.50 | 3.29 | 1 | 3.5 | 3.0 | 4.0 | 3.0 | 5.0 | 3.5 | 4.5 | 0.21 | 3.50 |
| 16 | 2 | 4.18 | 4.13 | 1 | 4.0 | 5.0 | 4.0 | 4.5 | 4.0 | 5.0 | 5.0 | 0.05 | 4.18 |
| 17 | 3 | 4.31 | 4.58 | 1 | 5.0 | 5.0 | 4.0 | 4.5 | 5.0 | 5.0 | 4.5 | -0.27 | 4.31 |
| 18 | 4 | 3.80 | 3.58 | 1 | 4.0 | 4.0 | 4.5 | 5.0 | 4.0 | 4.0 | 3.5 | 0.22 | 3.80 |
| 19 | 5 | 4.06 | 4.24 | 1 | 4.0 | 5.0 | 4.5 | 4.0 | 4.5 | 5.0 | 4.5 | -0.18 | 4.06 |

*Figure 7: NN Predict GPA (1-layer; using Backpropagation)*

Cell E6 will then update the current weight in cell E5 using array formula:

{=E5−$C$12*(SUM(E15:E39*$M15:$M39)−$B$12*E5)/COUNT($M15:$M39)}

(9)

where C12 is the learning rate and the SUM(…) term is the weight gradient. Copying cells E5:E6 to the rest of the columns completes the computations for other weights.

We can then activate Excel's iteration calculation feature (in the Calculation Option) and then change Start to "Yes" to set the recursive action between E5:L5 and E6:L6. The recursion stops when number of iterations reaches 100 or difference between successive computed values are not more than 0.001, where these values 100 and 0.001 being the two defaults limits given by Excel. For the GPA prediction scenario examined,

the initial training and testing MAE respective results of 0.17 and 0.23 did not attain the 0.14 and 0.16 results earlier found with Solver. However, these results improved to 0.14 and 0.16 respectively when the "Maximum iterations" is increased to 10,000 and "Maximum change" decreased to 0.00001. This is in line with the idea in Machine Learning that by increasing the number of layers and/or iterations, the computed function then produces a result that is more accurate to that of actuality.

With the 1-layer backpropagation process clarified, we will attempt to expand this to as many layers as desired. Backpropagation, as commonly termed in Machine Learning, is called such because the 1-layer approach had been shown (arising from the Chain Rule in mathematical differentiation) to be applicable to multi-layer models simply by working backwards from the last layer, one layer at a time. Each examined layer's input values are those which are forward-propagated (taking weighted sums) from preceding layers and error values backward-propagated (taking weighted sums, interestingly using the same weights) from the proceeding layer, with the last layer obtaining errors from the difference between predicted and actual output values.

Thus, each of the examined layer's input weights' gradients takes the same form as the SUM term in the earlier formula (9): averaging over all input values instances multiplied by their error term. Mathematical formulae involved can be quite onerous, but if done properly, spreadsheet portrayals are simple. The 2-layer NN backpropagation model using recursive computation is shown in Figure 8. As in the 1-layer model, there are two copies of all weights: current and next iteration. There are additional tables for error terms: one column each for hidden and final layers' output variables.

| | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Neural Network Predict** | | | 2-Layer (7-4-1) | | | | | | | | | | | | | | | | | | |
| 2 | GPA from Early Courses' Grade Points | | | | | | | | | Using Iterative Calculation | | | | | | | | | | Using Iterative Calculation | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Mean Abs Error | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | 0 | 1 | 2 | 3 | 4 | | |
| 5 | 0.14 | 0.17 | W1 | 0.52 | 0.45 | -0.03 | 0.25 | 0.57 | -0.05 | -0.11 | 0.03 | | | | | W | 0.64 | -0.07 | -0.40 | 0.17 | 0.14 | |
| 6 | Train | Test | W2 | 0.30 | 0.09 | -0.19 | 0.36 | -0.26 | -0.34 | -0.11 | -0.23 | | | | | Next W | 0.64 | -0.07 | -0.40 | 0.17 | 0.14272 | |
| 7 | | | W3 | 0.68 | 0.42 | 0.50 | 0.03 | 0.22 | 0.18 | 0.07 | 0.22 | | | | | | | | | | | |
| 8 | | | W4 | 0.00 | 0.67 | 0.15 | 0.83 | 0.51 | 0.05 | -0.09 | 0.01 | | | | | | | | | | | |
| 9 | | | Next: W1 | 0.52 | 0.45 | -0.03 | 0.25 | 0.57 | -0.05 | -0.11 | 0.03 | | | | | | | | | | | |
| 10 | | | W2 | 0.30 | 0.09 | -0.19 | 0.36 | -0.26 | -0.34 | -0.11 | -0.23 | | | | | | | | | | | |
| 11 | ReguTerm | | W3 | 0.68 | 0.42 | 0.50 | 0.03 | 0.22 | 0.18 | 0.07 | 0.22 | | | | | | | | | | | |
| 12 | 0.00 | | W4 | 0.00 | 0.67 | 0.15 | 0.83 | 0.51 | 0.05 | -0.09 | 0.01 | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | | | | | |
| 14 | Regu | Learn | Start | Select "Yes" to run | | | | | | | | | | | | | | | | | | |
| 15 | 0.01 | 0.002 | Yes | | C01 | C02 | C03 | C04 | C05 | C06 | C07 | Error | | | | Hidden Layer | | | | | Error | Out |
| 17 | S/N | YP | Y | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | Z1 | Z2 | Z3 | Z4 | Z0 | Z1 | Z2 | Z3 | Z4 | YP | YP |
| 18 | 1 | 3.49 | 3.29 | 1 | 3.5 | 3.0 | 4.0 | 3.0 | 5.0 | 3.5 | 4.5 | 0.0 | -0.1 | 0.0 | 0.0 | 1 | 4.2 | -2.4 | 6.5 | 7.6 | 0.20 | 3.49 |
| 19 | 2 | 4.14 | 4.13 | 1 | 4.0 | 5.0 | 4.0 | 4.5 | 4.0 | 5.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.1 | -3.1 | 8.1 | 8.8 | 0.01 | 4.14 |
| 20 | 3 | 4.35 | 4.58 | 1 | 5.0 | 5.0 | 4.0 | 4.5 | 5.0 | 5.0 | 4.5 | 0.0 | 0.1 | 0.0 | 0.0 | 1 | 5.5 | -3.2 | 8.6 | 9.5 | -0.23 | 4.35 |
| 21 | 4 | 3.78 | 3.58 | 1 | 4.0 | 4.0 | 4.5 | 5.0 | 4.0 | 4.0 | 3.5 | 0.0 | -0.1 | 0.0 | 0.0 | 1 | 5.6 | -2.4 | 7.3 | 9.4 | 0.20 | 3.78 |
| 22 | 5 | 4.05 | 4.24 | 1 | 4.0 | 5.0 | 4.5 | 4.0 | 4.5 | 5.0 | 4.5 | 0.0 | 0.1 | 0.0 | 0.0 | 1 | 4.9 | -2.8 | 8.0 | 9.0 | -0.19 | 4.05 |

*Figure 8: NN Predict GPA (2-layer; using Backpropagation)*

The formula for YP error (in cell V18), the difference between YP and Y, is given by:

=W18−D18 (10)

The YP errors, which are the differences between YP and Y (in cells V18:V42, Figure 8), are a major component in the partial derivative computations, as shown in the SUM term in formula (9) in the 1-layer NN case. In the 2-layer case, by backpropagation, it appears in the formula for the next weights associated with the hidden layer's variables.

The formula for next weight for Z0 (in cell Q6, Figure 8) is:

{=Q5−$C$15*(SUM(Q$18:Q$42*$V$18:$V$42)−$B$15*Q5)

/COUNT($V$18:$V$42)}
(11)

and it retains the structure of formula (9). This process can be repeated for all hidden variables' associated weights.

The YP error is backpropagated to give the Z1 error (in cell M18, Figure 8) using formula:

=R$5 * $V18 (12)

where R5 is the weight that linked Z1 to YP, and similarly we can compute the errors for Z2 to Z4.

The hidden layer errors Z1 to Z4 (in cells M18:P42, Figure 8) collectively is used in the computation of the weight gradients for the Xs and thus the formula for next weight for X0 (in cell E9, Figure 8) is

{=E5−$C$15*(SUM(E$18:E$42*$M$18:$M$42)−$B$15*E5)

/COUNT($M$18:$M$42)}
(13)

This process can be repeated using for input variables' associated weights.

For completeness, all the key formulas for the 2-layer NN are given in Figure 9 below.

| *Documentation* | | |
|---|---|---|
| MAE: Train | B5 | {=SUM(ABS(V18:V42))/COUNT(V18:V42) +B15*SUM(ABS(F5:L8),ABS(Q5:U5))/COUNT(F5:L8,Q5:U5)} |
| Test | C5 | {=SUM(ABS(V43:V52))/COUNT(V43:V52) +B15*SUM(ABS(F5:L8),ABS(Q5:U5))/COUNT(F5:L8,Q5:U5)} |
| X0-Z1: W | E5 | =IF($D$15="No",RAND(),E9) |
| Next W1 | E9 | {=E5-$C$15*(SUM(E$18:E$42*$M$18:$M$42)-$B$15*E5)/COUNT($M$18:$M$42)} |
| Next W2 | E10 | {=E6-$C$15*(SUM(E$18:E$42*$N$18:$N$42)-$B$15*E6)/COUNT($N$18:$N$42)} |
| Next W3 | E11 | {=E7-$C$15*(SUM(E$18:E$42*$O$18:$O$42)-$B$15*E7)/COUNT($O$18:$O$42)} |
| Next W4 | E12 | {=IF($D$15="No",RAND()/10,E12)} |
| Z0-YP: W | Q5 | =IF($D$15="No",RAND(),Q9) |
| Next W | Q6 | {=Q5-$C$15*(SUM(Q$18:Q$42*$V$18:$V$42)-$B$15*Q5)/COUNT($V$18:$V$42)} |
| Regularization Rate | B15 | <Input>, small value usually less than 0.5 |
| Learning Rate | C15 | <Input>, small value usually 0.1, 0.01, ..., 1.E-6 |
| Iteration Start | D15 | <Input>, Yes or No |
| Predicted Y, Y | C18, D18 | =W18, <Input> |
| X0, X1-X7 | E18:L52 | 1, <Input> |
| Z1 Error | M18 | =R$5*$V18 |
| Z0 | Q18:Q52 | <Input>, always 1 |
| Z1 | R18 | =SUMPRODUCT($E$5:$L$5,$E18:$L18) |
| Z2 | S18 | =SUMPRODUCT($E$6:$L$6,$E18:$L18) |
| Z3 | T18 | =SUMPRODUCT($E$7:$L$7,$E18:$L18) |
| Z4 | U18 | =SUMPRODUCT($E$8:$L$8,$E18:$L18) |
| YP Error | V18 | =W18-D18 |
| Predicted Y | W18 | =SUMPRODUCT(Q$5:U$5,Q18:U18) |

*Figure 9: Formulas of key cells in the NN Predict (2-layer; using Backpropagation)*

## 7. Discussion and Further Research

Conventionally, fixed but possibly differing weights are used to combine attributes and scores into evaluation scores, e.g. in student admissions. It is also plausible if for some reasons the weights used were forgotten and we want to reproduce them using only past record of applicants data and evaluation scores or if, in addition to evaluation scores, admission committee members also apply subjective judgments in granting admission (individually or otherwise). In any of these cases, we can easily apply linear regression and machine learning to determine the forgotten and implied weights.

Where there are sufficient data and with concurrence of academic administration, the admission decision process may even be largely automated by machine learning, and eliminate the need for admission committees to exhaustively review all but only randomly sampled cases, needed to refresh the weights. Of course, exception cases still need the attention of human decision-makers, particularly so if the consideration requires a qualitative measure of judgment, or is of a feature not easily quantified.

Another motivation of our work is to be able to apply the approach to Recognition of Prior Learning (RPL), specifically to help mature students with poor or no high school

education gain admission in undergraduate study programs. With some requirements and in lieu of others, universities can allow adult learners to take a small set of pre-specified courses pre-admission and use their aggregated results (with validation support from NN analytics illustrated in this paper) as supporting evidence for admission or even credit recognition. With these scenarios in mind, this paper had focused on the NN model with one continuous output variable and pre-selected structures.

In the interests of machine learning instruction, and particularly for those who are more technically inclined, these spreadsheets and the related concepts such as recalibration of the weights and the inclusion of additional variables can be used to formulate tutorial exercises or study projects. The key goal in this paper, however, is to find the simplest possible model that performs better than required. In light of that principle, objective function results should be carefully recorded and plotted against parameter values, number of hidden variables and number of hidden layers. This documentation would inform us at which value incremental changes would only bring marginal or no further benefit.

Proposed future work to this study includes a follow-up paper on categorical single and multiple output variables, namely in the domain of binary classification and multi-classification. With the simpler approach toward machine learning and neural networks using spreadsheets, we hope to bring even more techniques in the stable of machine learning to our classroom, including Clustering, and Decision Trees.

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## APPENDIX

Brief explanations of selected spreadsheet topics are provided here for easy reference on some salient but unfamiliar features. Further notes on the use of spreadsheet features and functions for modeling can be found in Appendix A of *Leong & Cheong* (2015).

### Cell Referencing

To speed up model building, formulas in some cells are often copied over to other cells. A leading cell in a top row of a table (below the header) may be copied over to cells in the same row but other columns right of it to complete of a series of similar cells, with some adjustments made where needed. The whole top row of the table is then copied (or filled) down to complete the table.

When copied to another cell, simple (i.e., relatively referenced; no $ signs) cell references in formulas would be changed by exactly the number of rows and number of columns that separates the source and destination cells. For example, if the destination cell is 3 rows down and 2 columns right of the origin cell, a C7 in the first cell will become E10 in the second cell.

Cell references can be prevented from changing when copied into another cell by using the $ sign. To disallow column change, just prefix $ to the column letter in the cell reference, and to disallow row change, do the same to the row number. You can also do both concurrently.

Staying with the illustrative example, (absolutely referenced) $C$7 in the origin cell would remain as $C$7 in the destination cell; (mixed referenced) $C7 would only have its row number changed in the destination cell as $C10; and (mixed referenced) C$7 would have its column changed in the destination cell formula as E$7.

### SUMPRODUCT (array1, array2, [array3, ..., array_n])

This function that multiplies ranges of cells (otherwise, also known as arrays) and returns the sum of their products. These arrays are either columns or rows of values. It multiplies the first value in the first array to the first value in the second array, the second value with the other second value and so on, and then adds all these values to give the output.

Logically, there must be at least two arrays. If there are more arrays, then the same logic applies with all the first values multiplied together, second values multiplied together and so on, and then summed. All arrays must naturally have the same number of values. Not numeric array entries are treated as zeros.

## Array Formulas

Array formulas are entered with *SHIFT + CTRL + ENTER*, instead of the usual *ENTER* key and would be displayed with the distinctive { } brackets. Array formulas may or may not involve array functions. Array formulas as so called because they involve computations with arrays and at times even return array outputs.

Many interesting computations can be done using array formulas, giving spreadsheet models that are more compact and easier to comprehend.

Example 1. Find the mean absolute error between the actual and predicted values of a variable, as in cell B5 of Figure 2 (see formula 5a).

Not using array formulation, we need to use an extra cell range to keep the absolute differences and then apply the SUM and COUNT functions as follows:

Set the formula for cell R15 as =ABS(S15−D15) and copy this to cells R16:R49.

Replace the formula in B5 with =SUM(R15:R39)/COUNT(R15:R39).

Alternatively, select cells R15:R49 and (entering using SHIFT + CTRL + ENTER) apply formula {=ABS(S15:S39−D15:D49)}. This array formula returns an array output.

More directly, without any need for cells R15:R39, we can apply array formula {=SUM(ABS(S13:S37-D13:D37))/COUNT(D13:D37)} to cell B5.

## Array Functions

Array functions are like normal functions except they return array outputs. As such, array functions are entered as array formulas with *SHIFT + CTRL + ENTER*, instead of the usual *ENTER* key and would be displayed with the distinctive { } brackets.

Example 2. Array function LINEST(knownY's, knownX's, [const], [stats]) returns the statistics that describe the least squares method for fitting a straight line to the given data set comprising knownY's and knownX's. If the optional variable const is TRUE or omitted, the intercept value is computed. Otherwise, the intercept value is assumed to be 0. If optional stats value is FALSE or omitted, then only the coefficients and the intercept of the fitted straight line are computed. If it is TRUE, four additional rows of statistics are computed. To key in the formula, first select a row with number of X's plus 1 number of columns for the FALSE optional stats case. For the other case, expand the selection to 5 rows.

Example 3. Array function TRANSPOSE(array) rotates the array by 90 degrees to make first row of the array as the first column of the output array, second row of the array ass the second column of the output array, and so on. It is important the size of the output array fits the expected output values.

Example 4. Array function MMULT(array1, array2) multiplies the rows of array1 to columns of array2 as in SUMPRODUCT and so on to return a matrix. The number of

columns in array1 must be the same as the number of columns in array2, and all cells in these arrays must contain numbers, no blanks allowed. So instead of applying many SUMPRODUCT functions in each cell of N15:Q49 of Figure 2 and select the cell range and apply formula {=MMULT(E15:L49,TRANSPOSE(E5:L8))}.

## Solver

Solver is available as a standard *Add-in* in *Excel*. That is, it only becomes available after you activate it by ticking Solver Add-in option in *File/Options/Add-ins/Excel Add-ins/Go*. Solver allows you to find the maximum or minimum value of an output variable (i.e., the objective function), subject to the constraints you specify. These constraints can include lower and upper limits on individual input values or their combinations (e.g., budget constraints).

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# Self-Healing of Cracks in Concrete with Bacteria

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## Abstract

During the service life of concrete structures, internal and external effects and micro-cracks occur in the structure. These cracks cause leakage of harmful substances into the concrete, deterioration of the strength and durability properties of the concrete, structural damages and crashes, and the high cost of maintenance and repair of the concrete structure. It is known that water-dissolved $CO_2$ reacts with $Ca^{+2}$ ions in the concrete and can repair the concrete by forming $CaCO_3$ (limestone) crystals with very little water solubility. However, for this type of self-repair to occur, there must be water in the environment and this repair can only be made if the cracks are too small. Recently, bacterial concrete methods which has ability to self-healing are used to overcome maintenance and repair costs. In 1994, the first study on the ability to self-healing with the extra materials that were added to the concrete during the production of concrete was published by Carolyn Dry of Illinois University. Eric Schlagen and Henk Jonkers who have been researching about self-healing concrete by adding bacterial spores and calcium lactate foods to the mixture while producing concrete have made a remarkable study in this field since 2006. Bacterial concrete, Bacillus bacterial spores in the medium of the water-activated nutrients and calcium sources in the range of appropriate pH values in the concrete due to the formation of a fibrous structure is caused by precipitation of calcite. Thus, with the precipitation of calcite, the bacteria are embedded in concrete and the concrete is provided to improve itself. In previous studies, it has been shown that the cracks and voids in the concrete are filled with the ethrengeite and C-S-H structure when the control and bio-based concrete samples examined by SEM and XRD are compared. In previous studies, it was

observed that mechanical strength and durability of the concrete is increased. It should be noted that the concentration of bacteria used in the solution and the ambient pH value is specified. Although conventional maintenance and repair methods are fast reacting, and short-term efficient, bacterial concrete method is sustainable, slow and long-term efficient. In addition, it is an environmentally friendly method compared to chemical repair methods and is expected to be among the remarkable materials of the future. The high initial cost leads to a reduction in producer demand, and the development process must continue to achieve the desired results and cost. As a result, it will be possible to obtain more durable structures by not wasting time, saving money and reducing the costs of high maintenance and repair. In other respects, it is a great advantage for sustainable development. Technical studies are continuing due to the high cost and laboratory test results of the bacterial family, as well as the impacts on the survival of the bacterial family. In this study, previous studies were evaluated, and some suggestions were made based on these studies.

**Keywords:** Self-healing concrete; micro-cracks; bacteria; humidification; bacillus pasteurii

## Introduction

Concrete, the most popular construction material that has been used in the world. But concrete has brittle mechanical behavior and environmental impacts effect physical and chemical structure of concrete, so this environmental impact is to cause to micro-cracks. Occurring mechanism of cracks which are inevitably in concrete due to its relatively lower tensile strength and action of different load and non-load factors may be varied including plastic shrinkage, drying shrinkage, thermal stresses, external loading and rebar corrosion or coupled effect of multiple factors (Souradeep et al. 2017). These cracks cause leakage of harmful substances into the concrete, deterioration of the strength and durability properties of the concrete, structural damages and crashes, and the high cost of maintenance and repair of the concrete structure. When growth of micro-cracks reaches from the surface of concrete to the reinforcement, corrosion occurs on reinforcement due to attack of aggressive agents (water, oxygen, $CO_2$, chlorides, etc.) which corrodes the reinforcement reducing its service life. The rate of aggressive agents' ingress into concrete is primarily dependent on the internal pore structure of concrete (Vijay et al. 2017). Therefore, it is more important to prevent these cracks at the start or it will become a major crack, however, to repair this crack is not an easy task so some alteration is needed in the construction material (Kulthe et al. 2018).

In 1994, C. Dry was the first who proposed the intentional introduction of self-healing properties in concrete (Van Tittelboom and De Belie 2013). In recent years, there are many alternative repair mechanisms and one of them is based on the application of biomineralization of bacteria in concrete. Biomineralization is a biochemical process in

which microorganisms stimulate the formation of minerals (Bundur et al. 2017). Bacteria induced mineral precipitation has been suggested by researchers as an alternative and environmental technique for crack repairing and sealing. The objective of this study is to summarize and compare the results of some researches published previously on properties and techniques of bacteria-based concrete which vary with the addition of bacteria. First, different theoretical approaches to bacteria-based concrete were explained. Afterwards, the results of some researches published previously on properties and techniques of bacteria-based concrete were summarized and compared.

## Theory

A variety of techniques is available but traditional repair systems have several disadvantageous aspects such as different thermal expansion coefficient compared to concrete and have impact on environment and health (Rao et al. 2013). Application of traditional crack repairing systems usually contains applying a cementitious material-based mortar bonded to the damaged surface, which can be especially time consuming and expensive in concrete structures due to mostly difficult to get access to repair cracks. Biotechnology and nanotechnology are used to improve the properties of concrete. Consequently, bacteria-based concrete has been suggested as an alternative and sustainable crack repair technique. The conceptual idea provided by bacterial crack healing mechanism is that the bacteria should able to transform soluble organic nutrients into insoluble inorganic calcite crystals which seals the cracks (Rao et al. 2013). Concrete has a rather aggressive medium due to its high internal pH, relative dryness and lack of nutrients for common bacteria needed for growth, however, some extremophilic spore forming bacteria can survive in this medium and increase the strength and durability of concrete (Rao et al. 2013). But, the bacteria will not survive once the cells become jammed by $CaCO_3$ crystals and the bacterial activity will also come to an end once all nutrients are consumed. Therefore, it can be concluded that even the bacterial approach will not allow an endless repetition of the healing process (Van Tittelboom and De Belie 2013).

Concrete durability and permeability has a strong relationship. Bacteria-based concrete biologically produces calcium carbonate crystals to seal cracks. Calcium carbonate ($CaCO_3$) that is a common substance found in rocks exists in environments such as marine water, fresh water, and soils. There are many techniques to heal properties of concrete, among these techniques' bacteria-based concrete that special strains of bacteria capable of precipitating certain chemicals are used is a relatively new technique. According to Rao et al. (2013), autogenous healing occurs because of hydration of non-reacted cement particles present in the concrete matrix once meet leakage water resulting in in closure of micro cracks, however, due to the variability of autonomous crack healing of concrete micro cracks can still occur. The bacteria used in concrete should be able to have long-term effective crack sealing mechanism during its lifetime serviceability. Recent researches about bacteria-based concrete focus to heal cracks

induced after 28-days of casting, which can be mentioned as an early age application for bacteria-based concrete (Bundur and Amiri 2016).

The mechanisms of microbially induced calcium carbonate precipitation (MICCP) can be achieved through different pathways like urea decomposition, oxidation of organic acids (aerobic process), or nitrate reduction (anaerobic process). Therefore, the effects of bacteria on concrete strength are variable. The precipitation rate of biological calcium carbonate is ideally influenced by concentration of calcium ions, pH of the solution, concentration of dissolved inorganic carbon and availability of nucleation sites. Alkali tolerant ureolytic strains, such as Sporosarcina pasteurii (Bacillus pasteurii), Sporosarcina ureae, Bacillus sphaericus, and Bacillus megaterium, that can decompose urea into ammonium/ammonia and carbonate ions (Equation 1) are the most commonly used bacteria in bacteria-based concrete. Bacterial urea hydrolysis requires oxygen to initiate bacterial activity (spore germination), which can be a restricting factor for deep crack healing. Nitrate reduction by different strains, such as Diaphorobacter nitroreducens, under oxygen limited conditions, denitrifiers use nitrate ($NO_3^-$) to generate $CO_3^{2-}$ and $HCO_3^-$ ions, which are necessary for $CaCO_3$ precipitation (Equation 2). The alkaliphilic strains, such as Bacillus cohnii, Bacillus pseudofirmus and Bacillus alkalinitrilicus, which can degrade organic compounds into $CO_2$ and $H_2O$, and $CO_2$ can be easily converted to $CO_3^{2-}$, and with the presence of $Ca^{2+}$, $CaCO_3$ can be formed (Equation 3).

$$CO(NH_2)_2 + 2H_2O \xrightarrow{\text{Bacterial urease}} 2NH_4^+ + CO_3^{2-}$$
$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad (1)$$

$$5HCOO^- + 2NO_3 \longrightarrow N_2 + 3HCO_3^- + 2CO_3^{2-} + H_2O$$
$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad (2)$$

$$Ca(C_3H_5O_3) + 6O_2 \longrightarrow CaCO_3 + 5CO_2 + 5H_2O$$
$$5CO_2 + 5Ca(OH)_2 \longrightarrow 5CaCO_3 + 5H_2O \quad (3)$$

There are some basic approaches for crack healing with bacteria: direct addition of bacteria into the fresh concrete; additions in the form of spores, immobilized form onto silica gel or activated carbon, encapsulated form, or using the vascular networks (Talaiekhozan et al. 2014). Concerns about the viability of the endospores within the improper and high pH environment of cement-based materials have led researchers to suggest encapsulation for the endospores. The encapsulation methods consist of enclosing the endospores in a protective covering. Thus, some encapsulation methods such as encapsulation in porous solids, capsule based, vascular based have improved for protecting the bacteria form improper environment conditions. The most generally used method, due to its ease and low cost, is immobilization in lightweight aggregates.

Capsule based approach consists of isolating culture medium inside discrete capsules. Once the capsules are ruptured for example by impact, the healing mechanism is triggered through the release and reaction of the bacteria in the region of damage. When the capsules survived the concrete mixing and casting process, it is vital that they survive within the highly alkaline cementitious matrix and that shell is not influenced by the encapsulated material. Vascular based approach inspired from blood vessels in creatures consist of isolating culture medium in a network of brittle hollow tubes which link the interior and the exterior of the structure. The type of encapsulation technique used effect the maximum allowable crack width which can be healed (Van Tittelboom and De Belie 2013).

## Results and Discussion

Bacteria-based concrete is a novel building material, so that physical and chemical properties of bacteria-based concrete need to be revealed by using some tests such as strength, water permeability, ultrasonic pulse velocity, chloride ion permeability, temperature differences. Experimental tests done by researchers showed that mixing bacteria into fresh concrete has some positive and negative effects on concrete properties. In this section, some physical and chemical, observational and experimental results on bacteria-based concrete is discussed.

MICCP ability of bacteria is one of the main subjects for bacteria-based concrete. Repairing of cracks in concrete structure occurs mostly early age, Souradeep et al. (2017) observed that bacteria repairs early age cracks more efficiently than later age cracks. Additionally, relations between healing age and repair rate is shown in Figure 1a where the crack healing ratio decreased remarkably along with the increasing of cracking age (Lou et al. 2015). Repair rate reduced with the extension of cracking age due to death of bacteria or lack of nutrients. It was reported by Rao et al. (2013), life-time of bacteria added directly into concrete mixture is restricted due to continue cement hydration resulting in reduction of cement sand matrix pore-diameter. Moreover, for effective crack healing both bacteria and nutrients mixed into concrete should sustain to continue the integrity of concrete mixture (Rao et al. 2013). According to Vijay et al. (2017), it was observed that encapsulation method protects bacteria from improper environment of concrete so that self-healing efficiency about crack closer and the amount of calcium carbonate precipitation. Bundur and Amiri (2016) mentioned that the chemical admixtures studied herein have no significant influence over the performance of the MICCP applications in bacteria-based concrete.

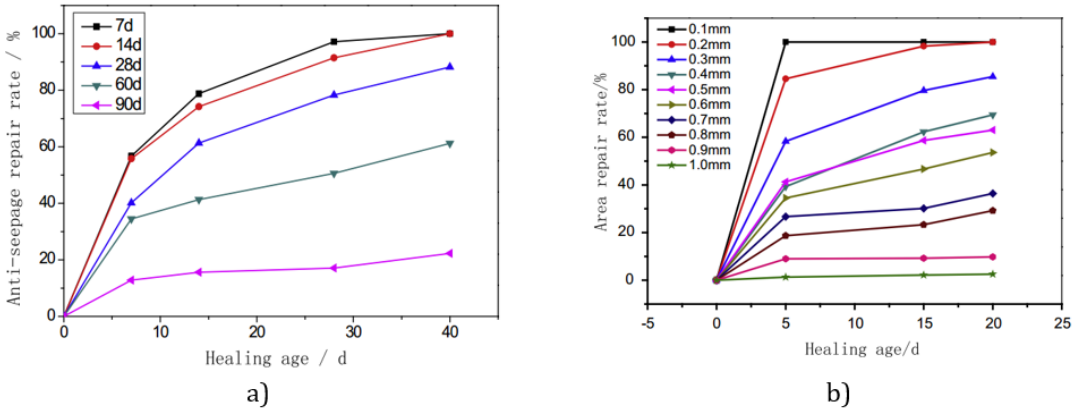


**Figure 1.** (a) Crack healing ratio of specimens in different cracking age (Lou et al. 2015), (b) the repair rate of specimens with different crack width after different repair time (Lou et al. 2015).

Many researches and Figure 2 support that cracks in bacteria-based concrete specimens fully filled with calcium carbonate provided by crack width up to 0.8 mm (Lou et al. 2015) or 100–200 μm (Souradeep et al. 2017), although it depends on several factors. When the average crack width increases, repairing of cracks are difficult and limited for bacteria repair agent (Figure 1b). To use crack area instead of crack width as measuring cracks was suggested by Souradeep et al. (2017). Not much is known about the interactions between admixtures and MICCP, further researches can be about these relations. It can be visualized by Scanning Electron Microscopy (SEM), which the addition of bacteria into the concrete can enhance cracks in concrete by mineral precipitation. Vijay et al. (2017) observed via SEM analysis that the different calcite crystals embedded with bacteria.

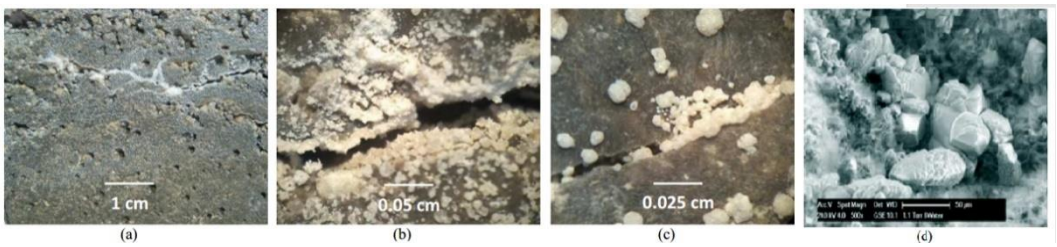


**Figure 2.** Four different pictures of microbiological precipitated calcium carbonate on the concrete cracks, (a) is without magnification, figure (b) with 20x magnification, (c) with 40x magnification and (d) ESEM picture of bacterial activates and precipitation of calcium carbonate with 20000x magnification (Talaiekhozan et al. 2014).

Chloride attacks make vulnerable of the service life of concrete structures. Vijay et al. (2017) were observed that using Sparcious Pasteurii and Bacillus Subtilis in the concrete

improve chloride ion permeability. Vijay et al. (2017) presented that charge passed in bacterial concrete specimen decreased by 55.8%, 49.9% and 48.4% with respect to normal concrete at the age of 7, 28 and 56 days. Several experimental results were stated that addition of bacteria into the concrete mixture increased water tightness, for the purpose that several researchers aimed to make concrete watertight. Water permeability and water absorption tests assess as a measure of durability (Souradeep et al. 2017). Water absorption depends on such as degree of hydration and fraction of open pores in the matrix. Lou et al. (2015) pointed out that water permeability in the bacteria series was about 10 times lower than that in non-bacteria series. Since, concrete structures may be in a wet condition now of crack appearance, the bacteria should be able to survive under wet conditions. Souradeep et al. (2017) observed that water curing had higher healing ratio compared to samples subjected to wet curing, moreover, for wet-curing the repair rate was slow and became almost same as water curing at late stage. According to Lou et al. (2015), water curing is to be the best way for bacteria-based concrete (Figure 3). Rao et al. (2013) stated that water permeability tests and ultrasound transmission measurements shows that bacteria-based concrete specimens are highly impermeable and have excellent quality compared with controlled concrete specimens.

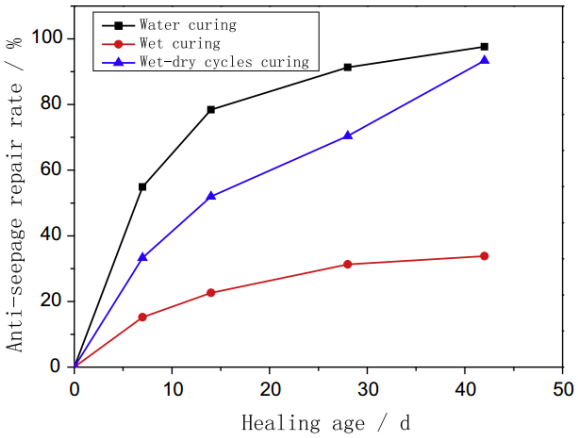


**Figure 3.** Crack healing ratio under different curing ways (Lou et al. 2015).

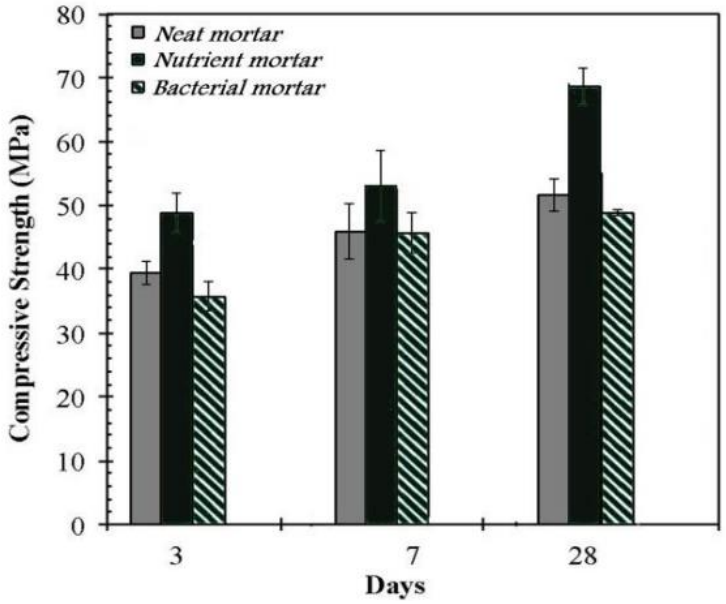


**Figure 4.** Influence of corn steep liquor (CSL) medium and bacterial culture on the compressive strength of mortar. The mass ratio of solution to cement (s/c) of 0.45 was used (Bundur et al. 2017).

In many practical application's other properties, such as durability, impermeability and volume stability, may be more important. However, strength of concrete is generally taken into consideration to give an overall picture of the quality. Since structure of concrete has porous, the elastic behavior is very important to guarantee the air and water tightness of the crack and prevent the occurrence of degradation. Retrieve in strength is of less importance, though, if the repaired crack is weaker than concrete matrix, later cracks may appear at the same location where the bacteria agent is already consumed. But, Souradeep et al. (2017) were pointed out that regaining strength was doubtful, since the strength regaining was not remarkably different for live and dead bacteria cells. In a study of Bundur and Amiri (2016), at any day of testing, nutrient mortar samples showed a higher strength than the neat mortar samples, nonetheless, addition of S. pasteurii cells in bacterial mortar resulted with a lower strength compared to nutrient mortar (Figure 4). Besides, in this study, they were mentioned that the chemical admixtures used there had no remarkable influence over the compressive strength for MICCP applications in bacteria-based concrete. Table 1 presents a summary of techniques and test results obtained from literature.

**Table 1.** Review of bacterial species, culture media, and major findings.

| Species of bacteria used | Culture media | Major Findings | Reference |
|---|---|---|---|
| Bacillus Subtilis | pH ≈ 7, at 370C, 105 cells/ml | a) For optimum solution of 35 ml the compressive strength is 39.16 MPa.<br>b) The specimens kept in air have negligible crack filled.<br>c) Water is necessary for successful self-healing. | (Kulthe et al. 2018) |
| S. pasteurii | urea-corn steep liquor (UCSL), pH ≈ 9, 30°C, 107–108 CFU/mL. | a) Industrial waste CSL and bacteria which can be potentially used for self-healing applications in cement-based mortars.<br>b) Substantial retardation was observed in initial setting of samples.<br>c) Addition of S. pasteurii cells with UCSL medium exacerbated the delay initial setting.<br>d) Addition of S. pasteurii cells in bacterial mortar resulted with a lower strength compared to nutrient mortar but did not result with a strength decrease relative to neat mortar.<br>e) The chemical admixtures studied there have no significant influence over the performance of the MICCP applications in cement- based materials. | (Bundur and Amiri 2016) |
| S. pasteurii | urea-corn steep liquor, pH ≈ 9, 30°C. | a) Even though the cracks were closed there was not significant improvement in flexural strength in bacterial mortar samples.<br>b) The compressive strength of bacterial mortar samples was like neat mortar, while it was less than nutrient mortar samples.<br>c) Cracks were fully filled with calcium carbonate in bacterial mortar samples while there was visually no precipitation in neat and nutrient mortar samples.<br>d) The use of waste material CSL did not have any negative impact on bacterial growth and supported the idea of using inexpensive waste material as a replacement for yeast extract.<br>e) Incorporation of UCSL medium delayed | (Bundur et al. 2017) |

| | | | |
|---|---|---|---|
| | | the initial setting time of cement paste | |
| Spore-forming alkali-resistant bacteria | 5.0 g peptone and 3.0 g yeast extract per liter of distilled water, pH = 7.0, 30°C, 109 cells/mL. | a) The crack healing ratio of specimens dropped significantly along with the extension of cracking age.<br>b) The healing ratio of different width cracks was different. | (Lou et al. 2015) |

Souradeep et al. (2017) concluded that strength reduction is basically due to alteration of microstructure because of reducing degree of hydration and poor distribution of hydration products caused by addition of nutrients and microcapsules. According to Bundur et al. (2017), incorporation of S. pasteurii cells in bacterial mortar resulted with increasing the compressive strength compared to the neat mortar, and on the other hand, using bacterial cells in bacterial mortar resulted with lower compressive strength than the nutrient sample. Rao et al. (2013) mentioned that a 25% increase in 28-day compressive strength of cement mortar was reached. Bacteria was able to seal flexural cracks as large as 0.3 mm, though there was not any strength regain due to cracks sealing (Bundur et al. 2017). In the present, initial construction cost may be high with using bacteria-based concrete as mentioned in many studies, but if infrastructures are built with bacteria-based concrete that is designed to perform under multiple damages, very low cost may be obtained over the life-time though initial cost may be higher than normal concrete.

## Conclusion

This paper focused on recent advances in the healing of cracks in concrete with bacteria. Bacteria-based concrete that will make a new revolution in the construction industry in the future may be an alternative to conventional concrete. Many researchers have suggested to use bacteria in concrete, due to environment friendly, sustainable process, be healed cracks and be improved concrete durability. The suitable bacteria can resist against improper environment of concrete that would die over time despite of the fact that encapsulated or immobilized in a protective carrier, such as high pH, temperature, serious limitation of water and mechanical forces during concrete mixing, for long durations. Bio-mineralization techniques which reduces the porosity so that $CaCO_3$ deposition acts as a barrier to harmful substances was confirmed by the experimental results, such as SEM analysis, the water absorption and chloride permeability. Bacteria-based concrete gives promising results in healing and sealing the cracks in the earlier ages of formation of cracks. Efficiency of bacteria-based concrete would mean that the durability and mechanical strength are regained fully or close to that of the normal concrete specimen.

The previous studies show that encapsulation method will present better results than direct application method and shows that bacteria using can improve the strength and durability properties of concrete. It is concluded that using bacteria in concrete improves compressive strength of concrete. While bacteria-based concrete has a lot of positive contribution to concrete properties, there is some problems to be solved in future researches. One of the problems is to find the suitable bacteria and nutrient medium, which can survive a restricted environment of concrete. Shrinkage, corrosion and carbonation properties of concrete need to be studied in detail due to have not been fully understood yet. Although experimental results have shown promising results in the lab, it is important to gather more results for simulating under real conditions such as non-ideal temperature ranges, high salt concentrations and at later ages of concrete element before applying self-healing concrete on a bigger scale. On the other hand, it is very hard to choose most efficient approach, because each research group uses its own test methods to assess the healing efficiency. We suggest developing standard test methods which would be very useful to compare the efficiency of one approach against another. In future studies will need to focus on more interdisciplinary research to produce genetically modified bacteria culture.

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# How Artificial Intelligence Can Augment the Collection of Scientific Literature

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## Abstract

This article describes the contribution of artificial intelligence (AI) to the literature collection process, which has become more efficient and more homogeneous. In this context, the researcher will receive his literature not only according to his field. Moreover, the literature is strongly linked to scientific and academic ambitions. AI through its deep learning techniques offers the possibility of speeding up the process of collecting augmented literature via an approach based on the annotation of scientific names and none-scientific names related to the field. AI provides original or reproduced research avenues with reliable and precise results. In this article, we have highlighted how to develop conceptual framework based on scientific and none-scientific names related to the area of expertise, all ensuring the reproducibility, reliability and accuracy of the study.

**Keywords:** artificial intelligence (ai), augmented literature, reproducible literature, reliable literature, accuracy literature.

## Introduction

In the era of numeric approved by scientific databases, scientific social network (researchgate, linkedin) and professional reports..., the volume of data increases considerably Cassel and al (2016). In a competitive world, having a data structure is not enough to obtain reliable results over time. Now, the scientific decision making is linked with the augmented data structure. A data structure requires more than the computing power with machine. On the other hand, the use of intelligent machines to organize and group the developed data increases the quality of the stored data.

In this context, a study conducted by Kaak (2019) confirms that almost 70% of the companies surveyed say that the quality of their data has an impact on the smooth running of their activities. At this point, the scientists are inspired, extrapolating the data source to the prospects their research is highly recommended.

The issue of this paper is how to build and improve the literature collection process by integrating the AI approach. The interest is to offer purely refined literature resources for scientific and academic purposes.

**Conceptual Framework**

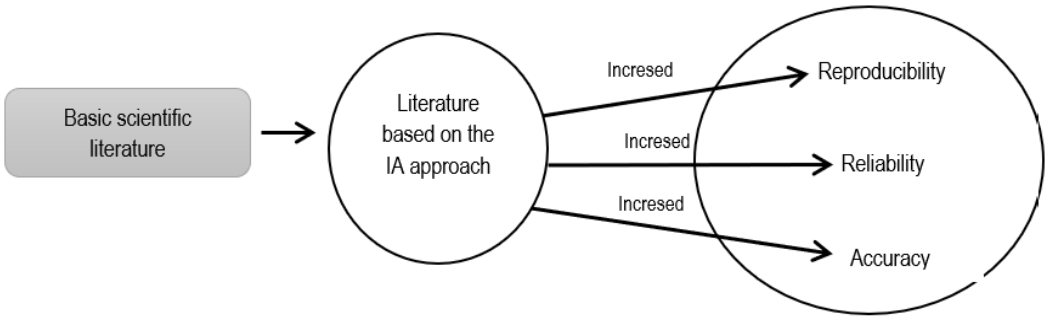



Fig 1. Framework of the study: Author developed

This study was divided into two parts. The first part carries the descriptive meaning via the definition of augmented literature and how is it constructed following the AI based literature approach, in ordered to extract the scientific and none-scientific names related to the field. In the second part, we focus on performance criteria for the development of the literature based on the AI approach.

**Approach to Enhance Literature**

The scientist's mission is to question each phenomenon observed continuously. In other words, the scientist keeps asking questions and looking for data that not only meets the requirements of the present but also about the future of society. In order to increase and adjust the human decision, the Brain Behind MECBot group defines augmented data as dynamic and agile information resources. At this level, the data must receive ingestion, cleaning, unification, integration, extraction and hydration processing with an almost real-time influx of new data developed.

An augmented data source serves to strengthen and transform the value of the research model developed. In this context, according to Miller and Brown (2018) faced with the technological means available; the extraction of knowledge from complex data generates information that optimizes concepts, searches for models, follows trends and associations, discovers the inefficiencies and predict outcomes. The following figure illustrates the evolutionary framework of the augmented scientific literature:

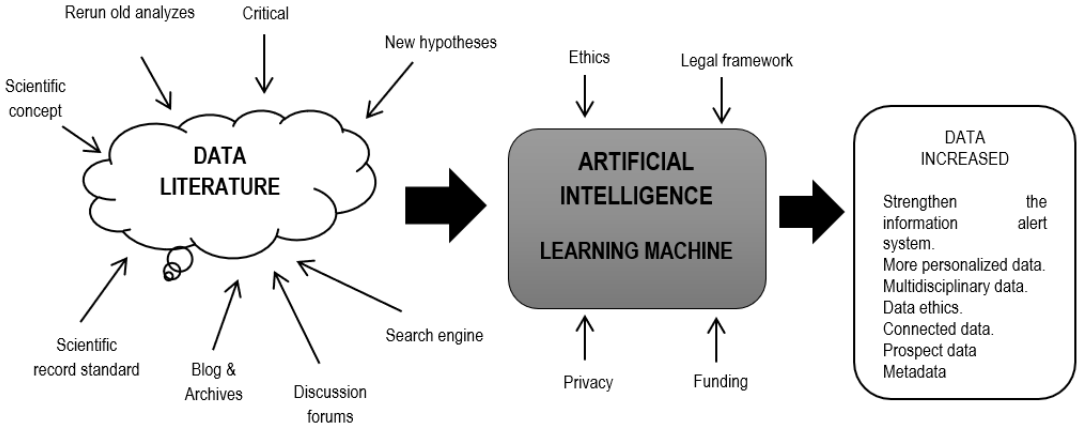



Fig. 2. The structure of the augmented literature

The development of discovery science Leach and (2009), has made scientific activity more valuable. However, with the advent of AI systems that can represent hypotheses and design data collection techniques based on scientific discovery. At this point, AI techniques speed up the process of analyzing gigantic data, which can be disseminated on all laboratory equipment. According to Gil and al (2014), analysis process includes the reduction of dimensionality and the functionality extractor to create high speed classifiers based on machine learning approaches, such as Bayesian networks or support vector machines.

The scientific activity is not limited in time or in space. It is considered as a continuous discovery circuit. At the time of scientific writing, the researcher can collect a set of conceptual information via automatic reading. This option can refine the search process and therefore the writing style. In this regard, renowned research begins with an in-depth analysis of the various sources of information selected.

The process of a literature analysis system begins with the extraction of scientific names. This will be very useful for bringing together all research contexts in the form of a set of resources: sentences, paragraphs, models or mathematical equations. These resources can help to enrich existing content or add new content to existing research projects such as the Encyclopedia project. In this context, the construction of augmented scientific literature is an operation in three stages:

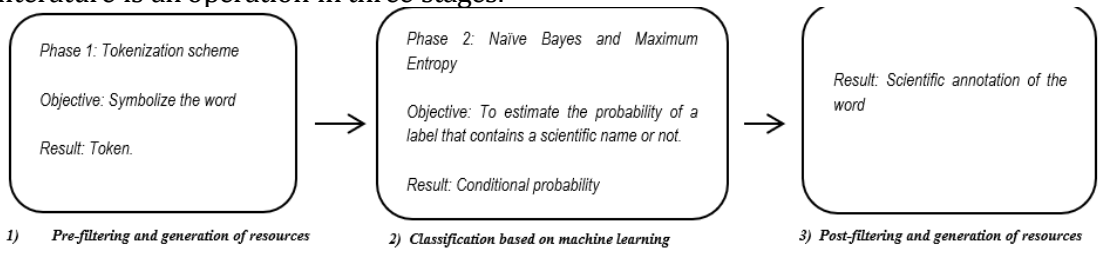



Fig. 2. The design process for augmented literature, Source Akella and al (2012)

The development of an augmented literature begins with a validation of the existing source of information. First, the text is symbolized via a trigram word which groups together three tokens. The tokens will be subjected to a qualitative evaluation to see if the words are well capitalized, abbreviated and check if the trigram has no common English words. Each filtered trigram will then be classified by a machine learning classifier as "scientific name" or " none-scientific name". The validation system takes into account the structural and contextual characteristics of the trigram. If the trigram is rejected by the rule filtering system, the first two tokens of the bigram of the same previous trigram will then be estimated. If it fails, the bigram analyzed can become a first name which will be classified accordingly if it is considered as a higher-order resource.

The second phase of the augmented literature design is estimated by the conditional probability of a label, belonging either to the rubric of scientific names or none-scientific names. This is based on contextual information about the meaning of the word. Once we get these conditional probabilities, we simply choose the label with the highest probability for a given string. This presents the closest name in terms of conceptual meaning related to the context of the study. This classification can be used in many natural language processing tasks such as text segmentation Neche and al (2019), markup of part of speech, language modeling and text classification.

The finished product is symbolized in a book which counts the chains derived from a structure of unigrams, bigrams and trigrams of words in the text. The neighborhood of scientific names is calculated according to the context of the words in the sentence. At this point, each researcher will have access to the documentation not only according to his area of expertise, but beyond his area. Behind each concept or terminology exists a model and an approach is therefore billions of resources that can be consulted and developed using the augmented literature approach.

**The performance criteria for augmented literature**

The literature in the various research fields evolves both in terms of theoretical and empirical models developed and even in terms of constructed statistical models. In this context, the scientific community is looking for a way to overcome the obstacles of research and to push the researchers to build scientific models and approaches of a higher order of reflection. At this stage, according to Wu and al (2018) the traditional guidelines for literature reviews are based on human screening, which may be subject to bias, lack of transparency, reproducibility and to human error. However, in the face of AI developments, learning machines combined with automatic natural language processing techniques can be used to ensure the reproducibility, reliability and accuracy of constructed literature.

**Increase Reproducibility**

The scientific community has not even reached a consensus, in which part of the scientific document will be placed the reproduction procedure. In standards, the peer-

reviewed article differs from other resources. First, the concept of the reproducibility of the literature does not mean the replica of the work. On the contrary, the literature will be subjected to a new experiment either according to new specific developed values, a new standard of calculation and constructed measures and either confirmation or none-confirmation of an extended hypothesis as a function of time and space. At this stage, the study conducted by [Cohen and (2016); Goodman and al (2016); Branco and al (2017); Clemens and (2017); Avidan and al (2019)] presents a number of conditions that must be met in order to reproduce a study via a natural language processing. A paper that receives natural language processing requires a set of criteria:

*Methodology*: the system must be clear and articulate, or there must be enough detail available to reconstruct the system exactly.

*Result*: there is an increasingly urgent call for validation and verification of the results of published research, both within the academic community and the general public.

*Robustness and generalizability*: the reproducibility will be obtained by strengthening and generalizing the body of the study, according to the variation of the basic hypotheses or in the experimental procedures.

*Inferential reproducibility:* the inferential reproducibility refers to the ultimate objective. According to which different scientists analyzing the same set of data on a larger population and who should reach similar conclusions.

*Assessment:* the reproducibility based on the assessment is used to ensure that all primary studies contain the appropriate information for the analysis and relevant to the field of research.

In a community with different cultural conventions, the need to enrich the literature with cases and experimental situations is very useful in many scientific fields. In this regard, Goodman and al (2016) suggest that the reproducibility of the methods, aims to capture the original meaning of the study. In another way, that is to say the possibility of implementing the experimental and technical procedures as exactly as possible, with the same data and the same tools. This is in order to obtain the same results broken down by demographic factors. In practice, things happen differently. The degree of reproducibility of a methodology is based on more detailed information. This information is not always kept by the investigator, such as on which machine have the samples being tested? ; In what order and on what day of execution?

In addition, the reproducibility of methodology requires to understand, how many analyzes were carried out and how the particular analyzes reported in a published article were chosen. All these parameters will be configured in the machine learning system. This is in order to take advantage from the level of detail required in the measurement process during the study.

According to Branco and al (2017), reproducing the results means obtaining the same results using the same procedures and the same experimental conditions. At this level, the reproduction of results will vary depending on the research area. For example, in the IT field; the results are determined by the initial conditions. On the contrary, in the social sciences, the models are subject to important stochastic components. This means the accumulation of evidence and data that can generate different results.

Indeed, two conditions must be fulfilled for an effective reproduction of the results Branco and al (2017). First, reproduce the phenomenon studied outside their original context. This situation could generate a false diagnosis, wrong procedures, a measurement error, a biased conception or a fraud, which constitutes the way towards a refusal to achieve the same produced results. The second efficient condition is that the reproduction of a study is not limited to the replication of the presence or absence of statistical significance, but beyond the evaluation of cumulative evidence and the evaluation of its sensitivity with significant biases.

The third important factor is presented by robustness and generalizability of the study. According to Clemens and (2017), a robust and generalized study signified the transportability of the empirical model of the study to other experimental contexts. In this context, through machine learning techniques, the investigator will be able to generate different tests and therefore have the possibility of extrapolating the study to an extended scale. The robustness of a study take different forms, as an example : a conceptual replication or pseudoreplication based on an open question, recoding or re-periodization of the same set of data by modifying the set of co-variables, the method of calculation of the standard error and updating of the data source with a set of original observations.

The robust and original scientific production should not only be classified in the category of new and distinctive studies. Therefore, the inferential studies are also recognized as studies which could also be classified among the most important studies. An inferential study is based on the exploitation of the content. This involves drawing qualitative conclusions from an independent replication of a study or thorough re-analysis of the original study. An inferential study differs in its objective from reproducible studies based on results and methods. As a result, the researchers can extract the same conclusions in all pre-existing studies, or draw different conclusions from the same specified original data structure. The figure below summarizes the different options using inferential studies in the reproductive process.

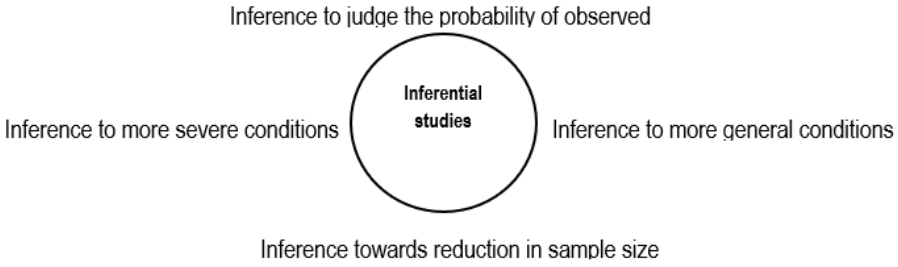



**Fig. 3.** The different cases based on reproducible inferential studies, Source Avidan and al (2019)

The last part of a reproducibility process is embodied in the systemic assessment of paper quality. In this step, we discover the scientific trends that have occurred in recent times. According to McKinnel and al (2019), in order to introduce scientific paper into the evaluation process, a set of conditions must be fulfilled:

*Construction of the algorithm*: a paper must integrate a section namely the implication of AI concept and machine learning in its conceptual structure. This part is described by a source code based on the taxonomy of scientific research carried out during the literature collection process.

*Context:* the contextual data must be provided in paper. In order to properly analyze the literature related to the field of study.

*Composition of the algorithm:* this criterion is the most essential for the analysis. It involves the analysis of the independent and dependent variables and if they are clearly established and indicated in the document itself.

*Data*: the data set used for the evaluation of the model must be explicitly described. If the private data set is used, it is necessary to explain the composition of this data and how it has been normalized for use in an AI scenario.

*Performance*: the performance of each model, algorithms or applications must be measured and presented with precision in the document.

In a research context based on the conditions presented above. The ultimate objective is to design a reproducibility approach based on AI. This is to identify the vulnerabilities of pre-existing studies and to what extent will be assessed in real time. Such an evaluation approach will speed up the process of developing theorems relating to the scalability of challenges and with an intention incited to a scientific revolution in each field of research.

**Increase Reliability**

The scientific landscape is constantly changing. This declaration transforms the research process into a scientific adventure. In this context, it's estimated that almost one million

articles are published each year or 30 articles each 30 seconds. In this situation, the researchers try to ensure reliability and assemble the right combination with regard to the literature introduced. A reliable study identifies the areas of research that could be considered as a reference support for the development of other studies.

According to Extance (2018) Iris.AI is one of a multitude of new AI-based research tools offering targeted navigation of the knowledge landscape. This platform helps researchers to validate existing scientific hypotheses to uncover hidden links between the results which may even suggest new hypotheses to guide experiments.

The researcher must know what the score should be assigned to a study in order to be classified in the categories of reliable studies. In this context, and in his daily column, the professor Seabright (2018) from the Institute for Advanced Studies in Toulouse indicates when a scientific study will have access to resources and how to introduce them into the list of augmented literature. This option strongly depends on a set of factors: (Mohajan (2017); Bobadilla and al (2018); Seabright (2018); Najafabadi and Mahrin (2016))

*Sample size*: the sample size should be larger than that of the original study sample.

*Study measure*: the measure must be carefully selected according to the consistency of the internal measure and see the quality of the inter-evaluators according to their judgments in relation to the phenomenon observed.

*The quality metric*: a reliable study is one that has a high citation index compared to the others.

*The control of random errors*: no study is perfect. The researcher must control the error structure composed of: material error (an impure sample, poor technical competence, etc.), observation error (instrument not included, perception bias of the observer, sampling error, etc.), conceptual error (calculation error, inappropriate statistical model, poorly specified assumptions, etc.) and discursive error (incomplete reports, erroneous credibility judgments, etc.).

*The stability of the results*: a reliable study that which treats the data in a uniform way in order to exploit all the stored data, and therefore to avoid falling into the information saturation area.

*Demographic factors*: a reliable study is strongly broken down by demographic factors such as age, sex and gender. This is to optimize the maximum of resources provided during the experimentation.

*Collaborative filtering*: a reliable study should not only be calculated on the basis of the problem quality addressed, either original or reproductive. The effective scientific production should rather affect the field of research by creating a new collaborative group. This is to create a common scientific trend.

## Increase Accuracy

According to Glasziou and al (2014) a very precise study, serves to control the quality of the methodology, the applicability of the results and to regulate the degree of falling biased before and during the research process. At this point, according to [McGrath and al (2019); Hinojo-Lucena and al (2019)] the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was developed to improve the quality of research reports and to regulate the meta-analysis process. The PRISMA statement affects many areas of research. The main objective was to help improve the completeness of the reports, compare the validity of the results and organize systematically the improvement notification of the drafting and publication process.

In this context, raising awareness of PRISMA DATA aims to know at what level scientific production progresses over time? And is there a productive relationship between the number of authors and articles? As a result, everyone is expected to be connected and involved in the publishing and writing process, starting with the study authors and going from peer reviewers to journal editors. At this stage, the production of a clear and homogeneous bibliographic study must comply with the editorial guidelines, ie in terms of approval and adherence.

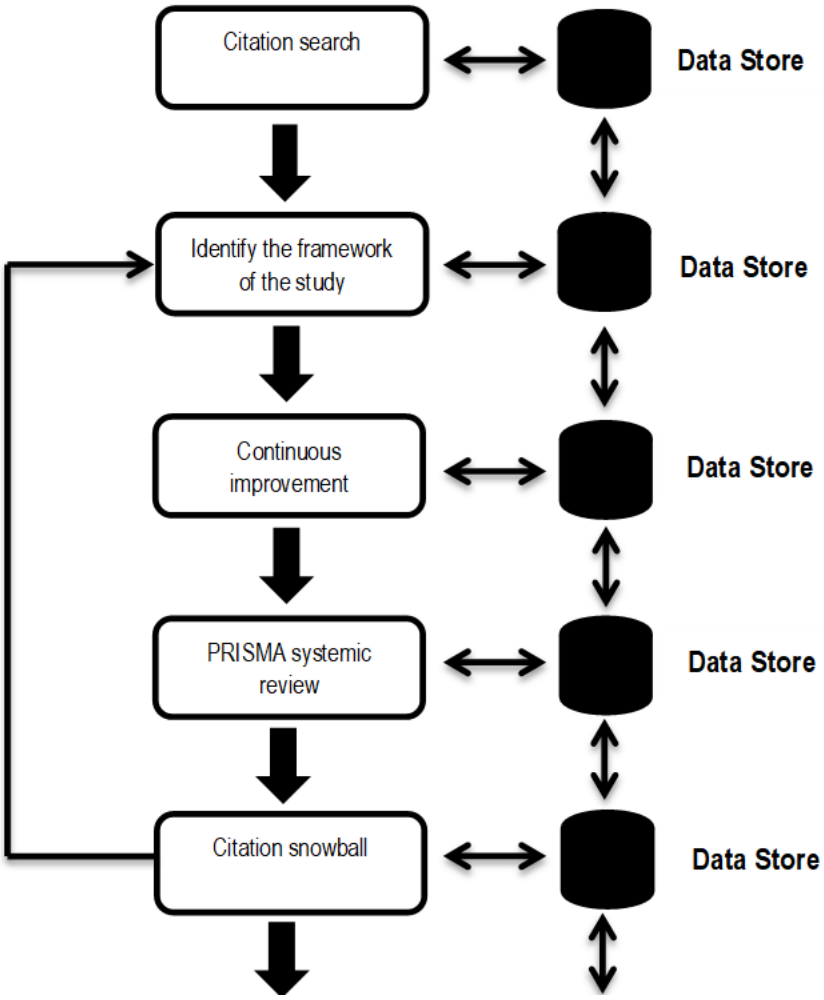
The techniques based on the natural language learning serve the PRISMA research community. At this stage, in order to be sharp in scientific writing, receive in real time the approval recommended by the review, with regard to the writing models which will vary according to the type of research carried out. This approval helps to stimulate the general use of the revision guideline, which could lead to a specialized framework guaranteeing the systemic evaluation of the study and to propose references linked to PRISMA standards.

For scientific purposes, the membership is the responsibility of the author to create well-reported and reproducible research. According to Dewey and al (2019) the studies submitted earlier to the review guidelines will be more adequate to be subjected to a reproductive process. This process is differentiated in a transparent manner according to the number of participants, the factors of comparison of results, the threshold of statistical positivity test adopted and the hierarchical and none-hierarchical intervention methods carried out….etc.

The PRISMA declaration is one of the systematic reviews (RS) in order to manage the evaluation and publication process. In this context, the initiative of International Collaboration for the Automation of Systematic Reviews (ICASR) is an interdisciplinary group with a common interest to maximize the use of technology to facilitate the transfer of scientific results to practice O'Connor and al (2018). The systemic automation is used to reassure continuous improvement of production, compliance with quality standards when writing, flexibility of use and combination of components, exploitation of relational resources and to share the evaluation code with its peers.

According to Beller and al (2018), SR process involves a variety of skills related to the field of information science, librarians, software engineers, statisticians, linguists and artificial intelligence experts. According to Tsafnat and al (2014) several tasks lend themselves to automation are: selecting titles and summaries, the search for full texts of studies, the extraction of data and even the collation of the meta-analysis results, the streamline research through the development of the writing protocol and graph evaluation report. Also the automatic filtering could be useful to quickly determine if a new eligible search has been performed and should trigger an RS update.

The automation of a manuscript is an operation which depends on many tasks. We have to analyze each task separately, from citation of references to reproducing paper. The following diagram summarizes the systemic review for the automating SR process.



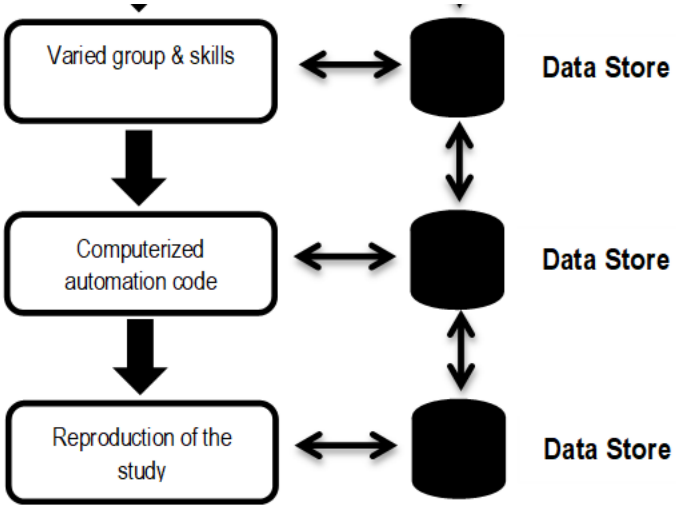



**Fig. 4.** The reproducible inferential process, Source Beller and al (2018)

The standards of scientific activity begin with an in-depth analysis of the literature related to the field of research. The researcher not only attempts to find a literature, but also to create a conceptual framework of the study. A conceptual framework subjected to an evaluation procedure allows researchers to receive comments that lead to continuous improvement of the literature. At the same time, automating a manuscript can facilitate the systematic evaluation of paper during production, in order to comply with PRISMA standards.

The development of an automation RS system should be flexible and rich in information. The flexibility is calculated based on the number of different components of the study, such as the appearance of new components and new variables, new test constraints and new hypotheses…and so on. All of these constraints transform and make the evaluation operation more efficient and will never be blocked at one level of the process.

A rich and coherent conceptual framework is one that involves a variety of multidisciplinary knowledge. In this context, with technological progress, scientific production continues to progress. Each automation technique should be shared, preferably by making the code available for free. The open source code makes it possible to build on previous work and thus facilitate the mission of reproducibility.

## Conclusion and perspectives

In the era of AI, the scientific production finds rigorous and very promising lines of research. The researcher not only needs to access recent documentary databases, but also to find resources in real time and in coherence with the intentions and the research objectives fixed. At this point, the digital science activity has become enriching and more structured with deep learning techniques.

The auteur will be assisted by advanced AI techniques via deep learning approach. The author will be informed which are the most advantageous and ambitious areas of reproducibility and what are the basic scientific concepts which must be articulated via empirical and theoretical tests. At same time, a robust and reliable study is one that receives a high score based on the most important study parameters. The production will be evaluated over time as the study progresses. For this purpose, AI offers a holistic approach to research. The researcher will receive comments that control his production processes from the start of the research activity. Consequently, the researcher will be able to measure the quality of his study before the final submission.

The development of a literature improvement model requires a colossal amount of data (big data). This is in order to detect unusual events in the data and therefore better understand the possibilities for future and original research. An empirical study using artificial intelligence techniques with the Payton software will be conducted with a set of indexed journals in order to bring out a base of enriching literature, all we respect the three performance criteria presented in this paper.

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# An Investigation on Improvements to Ultrasound Reactor Configuration for Extraction of Phytochemicals in Industrial Scale

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## Abstract

Industrial attentiveness and demand for natural bioactive compounds are rising continuously, regarding their growing commercial values in nutrition, pharmaceuticals, cosmetics and many other industries. The progress in ultrasound technology has spread the use of ultrasonication on a broad field of application areas, including extraction of bio-materials from plant sources. Ultrasound-assisted extraction is a powerful alternative to conventional techniques, in terms of extracting bio-compounds from variable kinds of matrices, higher efficiency, reduced extraction time, toxic-free operation, lower energy demand, lesser water consumption and better extract quality. Existing research pointed out that the reactor configuration is vital for maximizing the efficacy of extraction process, however basic reactor configurations that were mainly used in the literature may not be feasibly adapted to full-scale industrial applications. In this study, an investigation on possible improvements and modifications to existing reactor designs are discussed, such as detecting the optimum frequency range of ultrasound transmission depending on the material rheology and composition, possible modifications in beam-forming by means of frequency modulation and finally transmitting the waves in combination of different frequencies.

**Keywords:** ultrasound, frequency, extraction, phytochemical

## Introduction

Phyto means plant in Greek and phytochemicals are natural bio-molecules that are synthesized by plants for protection against external threats such as pollution, stress,

pathogens, UV exposure, etc. (Saxena et. al., 2013) There are more than 4.000 phytochemicals identified today that can be encountered in fruits and vegetables, grains, legumes, herbs and even fungi (Saxena et. al., 2013).

Phytochemicals are highly valuable chemical compounds as recent studies uncovered that, even if they are not essential nutrients for humans, they provide well-being by showing antioxidant properties, biocidal effects, modulating detoxification enzymes, stimulating immune system, regulating hormone system and anticancer properties (Saxena et. al., 2013). It is reported that individuals who regularly consume fruits and vegetables, carry %50 less risk of cancer according to their opposite counterparts and this benefit attributes to the consumption of phytochemicals (Boyer & Liu, 2004). Besides nutrition, phytochemicals also have application areas in industrial processes, such as food, cosmetics and pharmaceuticals. %90 of the extracted tannin today is used in tanning process of leather industry (Sivakumar, 2007).

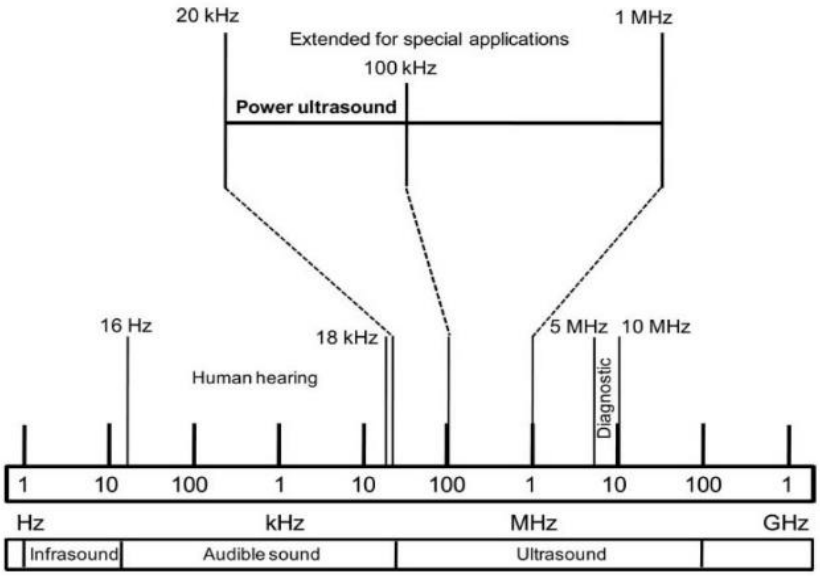
Extraction is a process that we encounter in our everyday lives and it dates back to ancient times (Panda & Manickam, 2009). Tea and coffee are both extracts which we obtain via thermal extraction methods, everyday. Basically, extraction can be defined as a separation process used for separating a substance of interest from a matrix. Undoubtedly, extraction is an indispensable fragment of industrial manufacturing today, especially in food production, cosmetics, nutraceuticals and pharmaceuticals (Panda & Manickam, 2009).

Conventional extraction techniques, generally referred to as thermal methods, are widely used for industrial purposes. Conventional methods that are in use for extraction of vegetal materials can be listed as follows (Vinatoru, 2001);

- Solvent Extraction
- infusion
- enfleurage
- maceration
- percolation
- extraction with hot fat
- Distillation
- water and steam distillation
- water steam distillation
- distillation of essential oils
- Cold Compression

Even though above given extraction methods have been applied successfully for years, two main driving forces have led the industry to search more advanced extraction techniques. First is the globally increasing energy costs. A faster method which can complete the extraction process in less time, also requires lower energy consumption than conventional techniques, will surely lower the production costs of the industry,

significantly. On economic aspect, installing conventional extraction units approximately requires %50 of the investment of a new production plant, and they represent %70 of the total energy consumption of a food plant (Chemat et. al., 2017). With these numbers in mind, any advancement in extraction technology means a lot to manufacturing industry. The second driving force is the increased consumer awareness. Consuming safer and more nutritive products (Aneja et. al., 2014) has been gaining popularity worldwide that manufacturers need to take notice. An innovative extraction technique which can eliminate the usage of toxic chemicals, operates with lower temperatures for obtaining heat-sensitive biomolecules and eventually provides higher extract quality (Chemat et. al., 2017), would probably better meet the market demands.




Ultrasound is basically defined as acoustic sound waves (emitted by probes), over human hearing range (> 20 kHz, see Figure 1), propagating through a medium, creating mechanical vibrations at a certain frequency. These waves can either be transmitted in a pulse-echo mode or continuous wave propagation, causing different effects in the bulk.

**Figure 1.** Frequency ranges of sound (Rastogi, 2011)

Ultrasound technology have found itself several practises in food manufacturing, as can be seen in Table.1

| Mechanical Actions | Chemical and Biological Actions |
|---|---|
| crystallization | biocidal effects |

| | |
|---|---|
| degassing | waste treatment |
| foam destruction | regulation of growth of living cells |
| extraction of flavourings | modification of enzyme activities |
| filtration | sterilization of equipments |
| drying | |
| freezing | |
| mixing | |
| tenderization of meat | |

**Table 1.** Application Areas of Ultrasound in Food Industry. (Mason et. al., 2005)

Applying ultrasound in extraction process is called ultrasound assisted extraction (UAE) (Vinatoru et. al., 2017). Extraction technology that uses ultrasound can be operated with lower temperatures than conventional thermal methods, hence degradation of heat-sensitive molecules can be avoided (Panda & Manickam, 2009). It is also considered as a green technology as green and lesser amounts of solvents can be used in place of toxic chemicals (Panda & Manickam, 2009). Besides giving the chance of improvements on safety and quality of foods, ultrasound technology also gives the opportunity to develop and design new products (Patist & Bates, 2008).

Besides all its beneficial properties, unlike from other innovative technologies in the field, ultrasound reactors to be used in extraction are not off-the-shelf products and need to be engineered application specific (Patist & Bates, 2008; Patist & Bates, 2008 ).

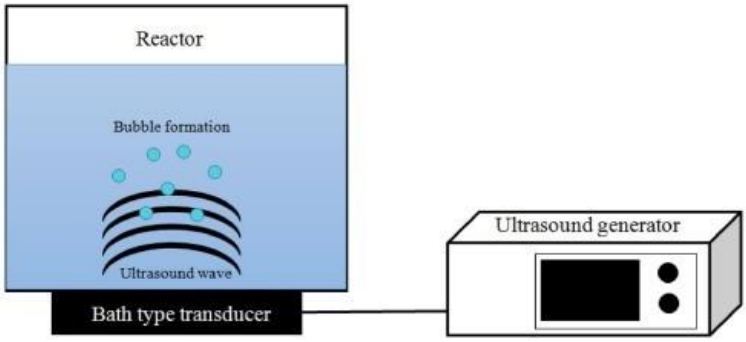
The presented article focuses on the ultrasound assisted extraction (UAE) of phytochemicals and possible applications on industrial scale by incorporating signal processing and analysis methods to optimize the extraction process. Difficulties in scaling the ultrasound treatment to an industrial application has been studied thoroughly (Tiwari, 2015) and problems associated with it have been noted. The following sections will discuss the induced effects of ultrasound applications in extraction, the variables influencing efficiency in terms of extracted yield and possible improvements that can be achieved by applying detection methods through the extraction process to identify the optimum values for the parameters.

## Background

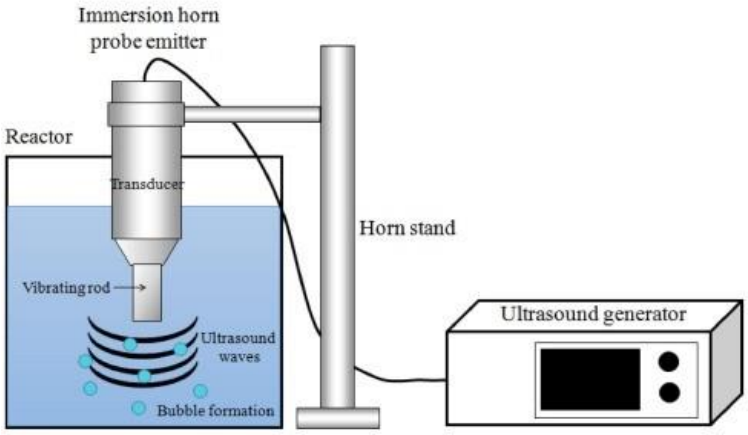
The principle behind UAE is the cavitation induced by the high power, low frequency ultrasound applied on a matrix, which is also referred as macrosonics. In other words, ultrasound applied with relatively high power (low frequency range 20-500 kHz, high

intensity greater than 1 W/cm2) have an impact especially on the chemical composition of food through cavitation (Awad et al., 2012) which enables the extraction of compounds that can later be used in various applications mentioned in the previous section. Cavitation (referring to as transient and unstable acoustic cavitation hereafter) by creating heat, pressure and turbulence (Patist, & Bates, 2008) cause cell disruption enabling the penetration of the solvent that will then let extraction of the target ingredient, until an equilibrium in the bulk is reached. Investigation of equations governing this phenomenon is out of the scope of the presented work, a comprehensive study will be done later on a specific type of food and its ingredients. Numerous studies can be found describing the basics of this well-known yet difficult to control physical event (Chandrapala et al., 2012). For instance, linear equations describing the propagation of ultrasonic waves disregarding compressibility were given, whereas the nonlinearities occurring especially in resonant cases (observed in high power ultrasound) were also studied (Laborde et al., 1998). Relating ultrasonic parameters such as wavelength to reactor geometry, resonant diameter to frequency (inversely proportional) already gives some hints on maximizing the cavities collapsing on the surface thus extracted yield (Patist, & Bates, 2008). Here, it was noted that the power dissipation would be the main concern in industrial scale applications. In another study, modelling of the acoustic pressure field (Moholkar et al., 2000), mathematical modelling and numerical simulations on the spatial distribution of the cavitation were investigated. Nevertheless, scaling the experimental setup up to an industrial production level still possesses problems when it comes to the generalization of the geometry, regression models and optimum process parameters, independent of the application and component of interest.

To provide a more detailed background of the previous studies, entire literature consists of empirical studies as the (transient) cavitation phenomenon is highly nonlinear in nature (Laborde et al., 1998). The basic outcome is that each experiment aims determining optimum conditions and parameters of a specific application, be it extraction of particular ingredients, decontamination or characterizing the physical properties of a given matrix. What is common in all these studies is the factors affecting the UAE efficiency, namely the reactor type (ultrasonic bath or probe/horn type) as illustrated in Figure 2, frequency of the emitted acoustic waves, applied power or intensity, duration, process temperature, solvent type, ratio and properties (Tiwari, 2015) and matrix size (Vinatoru et. al., 2001). In addition to these, probe design and geometry, utilizing multiple ultrasound probes to enhance cavitational effects can also be listed (Bilek & Turantaş., 2013; Awad et al., 2012), as well as ultrasound probe operating at continuous/pulsed mode focused on the sample to produce cavitation concentrated on a fixed area.




a. Ultrasonic bath type emitter.




b. Ultrasonic horn type emitter.

**Figure 2.** Ultrasonic Reactor Types (Thokchom et. al., 2015)

## Discussion

Cavitation phenomenon can be investigated by frequency analysis (Knorr et al., 2004) with its effects on extraction capabilities, to aid identifying the patterns and specific frequencies characterizing the constitution and physicochemical properties of food. Optimization of extraction through design of experiments and data-driven models for improvement of UAE on a specific phytochemical to provide insight to the possibilities of developing industrial scale devices will be the concern of research following the presented work here. In addition to that, detecting cavitation (and its intensity) alone with an improved design of ultrasonic transducers may further enhance such possibilities (Bornmann et al., 2014). That will in return lead to a study on harmonic content of the reflected echoes or related variables that may lead to identifying process behaviour for a specific application. For instance, detection of impulsive occurrences (since collapsing cavities can be considered as impulsive events) within a given duration

with time domain approaches might lead to a better understanding of when and at what intensity cavities collapse given a specific phytochemical.

Collapsing bubbles are very short duration and very intense events which can be considered as impulses that could be detected as transients in acoustic measurements. Signal processing tools for the analysis of data collected during UAE of several species and building data driven models on the processed information, making use of multi-disciplinary collaboration and knowledge are expected to provide novel approaches and scientific contribution to the field. To exemplify, high speed jets arising due to the hydro-dynamic cavitation are known to induce erosion even on the surface of the pump vanes, creating sudden malfunction in industrial processes causing unplanned downtime in the production. Some attempts had been made to understand and detect this phenomena to design an early detection system in different fields (Stopa et al., 2013; Čdina, 2003). Such approaches and studies could be beneficial to better understand the principles of cavitation in food processing.

The ultimate purpose here is to establish online monitoring of the extraction process by continuously measuring the parameters such as temperature, pH, acoustic intensity, acoustic field inducing transient cavitation in high power ultrasound to associate these with the mechanical properties of phytochemicals such as attenuation coefficient and acoustic impedance (Awad et al., 2012) and the solvent such as density, viscosity, homogeneity (Vinatoru et al., 2017; Vilkhu et al., 2008). In such an attempt, the results of the facts that the ultrasound waves are absorbed, scattered, reflected and finally induced cavitation which all cause certain amount of energy reduction will be taken into account. All these effects must be considered when adjusting the applied power to a specific matrix to extract the compound of interest with max. yield (Tiwari, 2015). Calorimetry (assuming that the temperature of the entire bath remains approximately constant or varies within a small range) can be used to get an estimate of the applied power. However, such assumptions might only be valid in laboratory-scale applications. To reach a better understanding of the necessities concerning an industrial scale reactor, specific analysis tools and detection methods will be utilized.

To integrate the bubble dynamics (Moholkar et al., 2000; Gogate & Pandit, 2004), a comprehensive discussion on sonochemical reactors and optimization of operating parameters (intensity, frequency, physicochemical properties of the medium) must be accomplished. Producing standard experimental setup does not sound reasonable and thus generalization of the design parameters and experiments are not realistic. Depending on the application, optimum parameters (affecting each other) must be found primarily with empirical approaches. Data derived from cavitational yield and other measurable parameters may reveal correlations between them. Concept of multiple transducers with an optimum geometric configuration leading to modulation of waves at desired frequencies may enhance the acoustic properties of the reactor. Viscosity of the solvent and free radical formation (due to the collapse of cavities in solvent (Soria &

Villamiel, 2010) are other concerns that must be dealt with when it comes to the estimation of the optimum settings.

## Conclusion

Ultrasound Assisted Extraction of phytochemicals at its current stage was investigated and it was noted that using the process data that is produced by a nonlinear system, fitting to 2nd order polynomials, attempting to design regression models and being highly determined by the physical and biochemical properties of the material may produce conclusive results in small-scale applications but will not be applicable in industrial production plants. There is still room for improvement especially on the data analysis and processing part of the parameters, such as identifying the relation between vapor pressure within the bubbles and intensity of collapsing bubbles, surface tension of the bulk and threshold of transient cavitation (Tiwari, 2015), as well as the solvent viscosity.

In addition to what has been mentioned so far, multi-frequency systems may help to understand the combined effects of ultrasound transmitted in different frequencies. By doing so, data corresponding to extracted compounds may be related to modulation and frequency bands. Sonication duration must be adjusted in such a way to maximize the extract while hindering the occurrence of free radicals, or by making use of other methods (gas injection or mixtures of solutants must be preferred). Applying signal processing techniques on UAE will be the concern of further research following the presented study.

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# Smart Cities, Big Data, Artificial Intelligence and Respect for the European Union Data Protection Rules

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## Abstract

The importance of cities and their populations grow more and more, as well as the need to apply ICT in their management to reduce their environmental impact and improve the services they offer to their citizens. Hence the concept of smart city arises, a transformation of urban spaces that the European Union is strongly promoting which is largely based on the use of data and its treatment using Big data and Artificial Intelligence techniques based in algorithms. For the development of smart cities it is basic, from a legal point of view, EU rules about open data and the reuse of data and the reconciliation of the massive processing of citizens' data with the right to privacy, non-discrimination and protection of personal data. The use of Big data and AI needed for the development of smart city projects requires a particular respect to data protection regulations. In this sense, the research explores in depth the specific hazards of vulnerating this fundamental right in the framework of smart cities due to the use of Big Data and AI.

**Keywords:** smart cities, big data, artificial intelligence, European Union data protection rules

## Introduction

Cities are large population centres which, in the medium term, are expected to concentrate even more inhabitants and percentage of the population. UN estimates suggest that cities currently consume 78% of the world's energy and produce more than 60% of greenhouse gas emissions despite covering less than 2% of the Earth's surface. In this regard, it is essential to take measures to avoid such concentration of emissions in cities and relevant measures are already being taken at the global level and by the European Union.

The European Green Deal claims for the EU to be "climate-neutral" by 2050[12], not contributing to global emissions as a whole. The success of the smart city projects discussed in this paper will be fundamental to achieve that goal.

Due to the growing trend, mentioned above, of population concentration in cities, it is essential to have mechanisms and technologies that guarantee the sustainability of urban developments, respect for the environment, rational use of available resources and adequate treatment of the waste generated. It is therefore essential to make a decisive and global commitment to *smart cities*, to improve the provision of public services and to meet the challenges that, in the medium term, must be faced at world level in the management of urban spaces.

As an approach to the concept, we can say that an smart city is a place where traditional networks and services become more efficient thanks to the use of Information and Communication Technologies (ICT) for the benefit of city inhabitants, businesses and the environment.

The smart city means going beyond the use of ICTs just to make more rational use of resources, improving the environment and reducing emissions or waste generated in large urban areas. The implementation of a truly *smart city* involves much more: the optimisation of urban transport networks and the movement of vehicles and people, the improvement of essential services for citizens such as water, gas or energy supply, the restructuring and rethinking of urban planning, carrying out much more efficient management of urban waste or reducing energy consumption by committing to smart lighting in the urban public domain, as well as public-private collaboration to ensure that

[12] European Commission (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on "The European Grean Deal", COM/2019/640 final, adopted on 11 December 2019. The European Green Deal is the EU's response to climate and environmental change and the social challenges they bring. It is a complex challenge that requires the mobilisation and support of citizens and governments in all EU countries. The Deal promotes the efficient use of resources by moving towards a clean and circular economy and incorporates a roadmap with a series of actions proposed by the EU. In addition to being climate-neutral by 2050, the Union proposes: to reduce pollution, thus protecting human life, fauna and flora (according to experts we are experiencing the sixth mass extinction with the accelerated loss of animal species, and the first caused by humans. Since 1500, more than 320 terrestrial vertebrates have become extinct and the population of the surviving species has fallen by an average of 25%); helping companies become world leaders in clean products and technologies, as at present European industry uses only 12% of recycled materials; and helping to ensure a fair and inclusive transition. Some of the benefits of the Green Deal for citizens in terms of well-being and improved health would be: less waste, by producing reusable or recyclable packaging through the Circular Economy Action Plan [European Commission (2015). Communication from Commission "Closing the Loop: an EU Action Plan for the Circular Economy, COM (2015) 614 final, adopted on 2-12-2015]; healthier and more environmentally friendly food by reducing pesticides and fertilizers; promoting clean vehicles by providing more charging points for electric cars; better public transport alternatives, as transport accounts for 25% of emissions; renovation of homes, schools and hospitals; reducing energy bills for buildings, which currently account for 40% of total consumption; better air, water and soil quality through decarbonisation of the energy sector, which accounts for over 75% of EU greenhouse gas emissions. Finally, we must stress that the European Green Deal is accompanied by significant funding through the Just Transition Fund, which is estimated to mobilise up to EUR 100 billion in investments over the period 2021-2027 in a transition fund to convince hesitant EU countries, especially those in the East.

this management model is implemented at both levels of action and to increase citizen participation both in improving the model and in its governance and transparency.

Cities have begun to take advantage of the Internet of things[13] and to use ICTs to create more efficient spaces, as we have already mentioned, and not only in the environmental aspect, but also in the social, economic or operational aspects. On the other hand, the smart city interacts with the citizens, in such a way that the information generated by the connected citizens themselves directly facilitates both the organisation and management of the daily services and processes addressed to them by the Public Administrations and the effectiveness and efficiency of public management, thus complying with such principles that must govern it[14], and facilitating many of the rights of European Union citizens set out in the Charter of Fundamental Rights of the European Union[15]: the rights of the elderly "to lead a life of dignity and independence and to participate in social and cultural life" (art. 25), the right to integration of persons with disabilities wich can benefit, in a *smart city* from "measures designed to ensure their independence, social and occupational integration and participation in the life of the community" (article 26), to (digital) health care (art. 35), environmental protection (art. 37), and consumer protection (art. 38), to vote and to stand as a candidate at elections to the European Parliament (art.39) and municipal elections (art. 40), and finally the right to good administration (art. 41).

## Literature Review

According to the European Parliament, smart cities can be identified and classified according to six main axes or dimensions: smart governance, smart economy, smart mobility, smart environment, smart people, and finally, smart living[16]. Therefore "a city can be defined as 'smart' when investments in human and social capital and in transport and ICT infrastructure contribute to sustainable economic development and to

[13] The Internet of Things has been defined by the European Data Protection Committee (former Article 29 Data Protection Working Party), in its Opinion 8/2014, adopted on 16.09.2014 on "Recent Developments on the Internet of Things" as
"an infrastructure in which billions of sensors embedded in common, everyday devices – 'things' as such, or things linked to other objects or individuals – are designed to record, process, store and transfer data and, as they are associated with unique identifiers, interact with other devices or systems using networking capabilities". GONZÁLEZ DE ALEDO CASTILLO (2019) defines them as "a series of sensors incorporated into devices or objects of people's daily lives which, connected to the Internet and/or between each other, allow the exchange and interaction of different data that make it possible to generate information that can be useful both for the owner of such data and for the rest of the participants in the chain -device manufacturers, application developers, Internet service providers, etc.-".

[14] In the case of Spain, art. 103 of the 1978 Spanish Constitution include effectiveness among the principles which guide the action of the Administration, and so do art. 3 of Law 40/2015, of 1 October, on the Legal System of the Public Sector wich include also efficiency.

[15] The EU Charter of Fundamental Rights was adopted as a formal Declaration on 18.12.2000, but it became legally binding in every EU member state, with the entry into force of the Lisbon Treaty on 1 December 2009.

[16] European Parliament (2014). "Mapping Smart cities in the EU", a document produced by the European Parliament's Directorate-General for Internal Policies in January 2014, p. 19,
https://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf (accessed 21-6-2020).

improving the quality of life, with rational management of natural resources, through participatory governance" (VILLAREJO GALENDE, 2015).

From 2012, the European Commission launched a specific initiative for the development of smart cities called "Smart Cities and Communities-European Partnership for Innovation", providing 365 million euros for innovative ideas and projects in the field of energy, transport and ICT in urban areas and demonstrating Europe's commitment to the sustainability of its cities.

There are currently numerous European initiatives aimed at boosting the digitisation of cities and successfully addressing the transformation of cities into smart cities, such as those carried out by the European Innovation Partnership on Smart Cities and Communities (EIP-SCC), the Digital Transition Partnership of the Urban Agenda for the EU, or the Horizon 2020 projects, as well as the above-mentioned initiatives included in the European Green Deal.

In the case of Horizon 2020, the eighth European Framework Programme for Research and Technological Development (H2020)[17] is a programme that funds research and innovation projects in various thematic areas in Europe, with a budget of almost 80 billion euros for the period 2014-2020. It is open to researchers, companies and technology centres as well as public entities, and integrates all phases of a project, from the knowledge generation phase to the transfer of knowledge to activities closer to the market. However, as these are fragmented projects and solutions, their results and impact are limited and it is necessary to develop global and integrated solutions for smart cities, which combine low carbon and energy efficiency with citizen participation and transparency in management. In this sense, the "Join, boost, bustain" movement mentioned above becomes fully valid, as well as its objective is to support the creation and extension of digital platforms and open digital solutions throughout the EU, which have the characteristics of being interoperable, cross-sectoral and cross-border.

The aforementioned European Innovation Partnership on Smart Cities and Communities (EIP-SCC), which was established in 2012 and has since helped to bring together stakeholders in six action groups and to generate calls for projects called *Smart Cities Lighthouse*[18] under the Horizon 2020 programme, reflects this EU effort to maximise efficiency and flexibility through interoperability and standardisation, as a first important step towards a future European Union policy on cities.

By 2050, two thirds of the world's population will live in cities and in Europe, almost 75% of the population currently lives in urban areas of different sizes, with European cities being major contributors to energy consumption and pollutant gas emissions as we have highlighted, so it is essential to minimise their climate impact. On the other

[17] Data on the projects and funding of the Horizon 2020 Programme can be found at https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-dashboard
[18] These projects are available on the EU Smart Cities Information Cities website at: https://smartcities-infosystem.eu/

hand, we cannot ignore the fact that cities are the main engines of the Union's economy, and the main responsible for the creation of growth and employment. In this respect, EU initiatives are aimed at promoting more attractive and competitive, healthier and sustainable urban areas in which to live, integrating environmental protection and the fight against climate change. The initiatives being implemented are very numerous and diverse. Some sectors where notable progress has been made are the area of Smart Grids, energy efficiency and the digitisation of the water sector. In relation to smart grids, the Smart Grid working group is examining the possibility of establishing a common format for the exchange of energy data at EU level as a basis for an interoperability framework. On energy efficiency, the EU has defined a readiness indicator for smart buildings, which aims to measure the ability of buildings to use digital technologies and electronic systems to optimise operation and interaction with the grid[19].

For its part, the European Economic and Social Committee has drawn up an Opinion[20], in which, among other issues, it establishes the need to carry out the integration of the following fundamental pillars in order to achieve a more advanced and effective model of smart cities:

technologies and instruments for energy efficiency and the integration of renewable sources;

dissemination of technology and connectivity platforms to create the new digital services systems;

new digital services to improve the quality of life and work of citizens and businesses;

modernisation of urban infrastructure and urban redesign;

education and training of citizens, enterprises and the public sector in digital skills; and

an economic and financial sustainability model for investments.

Recently, in January 2020, the European Union published “Living.in.EU – The European way of digital transformation in cities and communities” or "Join, boost, sustain" Declaration to lay the foundations for the digital transformation of European cities. This is an initiative signed by representatives of EU cities and supported by the Committee of the Regions and the European Commission.

The Declaration comes at a time when cities and communities in the European Union are facing an increasing number of challenges and are coming together to do so[21]. It proposes to address these challenges through digital solutions based on locally generated data, which are essential for providing better services in areas such as mobility, public

[19] See further information at Smart Readiness Indicator for Buildings (SRI): https://smartreadinessindicator.eu/
[20] European Economic and Social Committee (2015). Opinion of the on ‘Smart cities as drivers for development of a new European industrial policy’ (own-initiative opinion) (2015/C 383/05), adopted on 1-7-2015
[21] Some European initiatives in this sense are: EUROCITIES- network of large European cities; Open and Agile Smart Cities (OASC); or the European Network of Living Labs (ENOLL).

services and energy efficiency, stressing the need for cooperation between the different actors involved (through multilevel governance in the EU) in order to boost innovation, enabling citizens to be the focus of public policies that provide efficient and cost-effective services. It insists on the need for sufficient public and private investment in digital services, technologies, infrastructure and skills in order to achieve this goal, to ensure technological leadership of the EU (in the words of the declaration, since no such leadership currently exists at global level) while respecting European values and diversity, as well as the digital rights of individuals. It includes clear commitments such as the creation of a joint investment plan focusing on digital solutions; the creation of standards focusing on ensuring interoperability of data and platforms between cities; and bridging the digital divide by promising to provide all citizens with the digital skills they need to be able to benefit from the services and solutions offered by the smart cities[22].

It is important, as the declaration underlines, that the public has confidence in the systems to be implemented in smart cities, for which the data must be used responsibly through digital platforms that guarantee the quality, security and privacy of such data collected and processed for the better functioning of the cities. In this sense, the core of the declaration is the implementation and expansion of open, interoperable, cross-sector and cross-border platforms, as a means of driving the digital transformation. The aim is to provide guarantees for technological sovereignty in the EU, and to promote the joint creation of digital solutions in order to avoid specific disparate and scattered technologies isolating and blocking European cities.

Regarding the regulation of smart cities by the European Union, public institutions have a key role in driving new developments and generating new opportunities for companies in the smart city sector. In this respect, the role of the EU is clearly fundamental, given the scope of its regulation and the possibilities it has for harmonising the legislation of its Member States in many of the aspects relating to smart cities, as well as the capacity, which we have pointed, to finance the initiatives it launches. The international scope that the EU represents and the understanding of its role in this process means opening up opportunities at international level for companies that have innovative and valuable products and services at Union level.

We therefore consider that the two main functions of the EU in relation to smart cities are, firstly to promote and fund initiatives that facilitate the development of projects in this field, as we have seen in the previous section, and secondly the function of harmonising or coordinating the legislation of the Member States to make this possible.

Only with the intervention of the EU a homogeneous legal framework can be created to provide a model of smart city that can be homologated throughout its territory. The main binding regulatory instrument for the Member States with a view to achieving this

[22] See Comitee of the Regions (2020). Opinion of the European Committee of the Regions "Digital Europe for all: delivering smart and inclusive solutions on the ground" (2020/C 39/18), adopted on 5-2-2020.

objective are the European Directives, but also other mechanisms such as the European Regulations (to establish common guidelines for the approval of certain products or technologies, a particularly important issue in the field of the Internet of Things or Big Data, aspects in which European regulations are already advanced, as we shall see later), the creation of seminars or working groups to share ideas through the publication of White Papers[23], etc.

The most immediate benefit of this policy is that it creates a large internal market that increases the attractiveness of EU business and is aimed at this as we will see the Digital Single Market as a parallel EU initiative. An example of this action is the European Framework of Reference for Sustainable Cities (RFSC)[24], a web tool or application designed to enable all European cities to have a common conceptual framework when assessing and planning policies aimed at development and sustainability, fields in which the sector of smart cities is a key player. The Framework defines in detail 30 sustainability objectives for European cities, and provides online tools for public and private actors to assess the situation of their cities in relation to these objectives. Among them we can highlight:

Spatial dimension: sustainable urban planning, spatial equity, sustainable mobility, territorial resilience, heritage preservation, quality public spaces.

Government dimension: continuous improvement processes, citizen participation...

Social dimension: inclusion, equity, access to housing

Economic dimension: green growth, local economic resilience, sustainable consumption and production

Environmental dimension: mitigating climate change, adapting to climate change, reducing pollution, conserving resources...

The concept of the smart city comprises multiple aspects, linked in terms of their purpose but very diverse in terms of the regulations that govern them. Without wishing to be exhaustive, if we analyse the smart city we will have to look in depth at aspects such as personal data protection, the digital single market, open data, public procurement, the use of artificial intelligence and its impact on decision-making, the impact of ICT on our current model of liberal democracy, citizen participation, the concept of the accessible city and the inclusion of people with disabilities or digital administration.

[23] European Commission White Papers are documents containing proposals for European Union action in a specific field. They sometimes follow on from published Green Papers, which aim to launch an EU-wide consultation process. The purpose of White Papers is to launch a debate with the public, interested parties, the European Parliament and the Council in order to reach a political consensus. The Commission's 1985 White Paper on completing the internal market is an example of a project that was approved by the Council and led to the adoption of far-reaching legislation in this field.

[24] See http://rfsc.eu/ for this online application.

In this sense, the concept of smart city "can be considered a transversal phenomenon that can, and must, be approached from multiple branches of knowledge" (VELASCO RICO, 2019). This author defends that, despite the fact that the concept is not legal and has a poorly defined profiles "for the reserchers of Administrative Law, it allows the limits of the discipline to be extended, in the sense that smart cities invite Administrative Law to act in scarcely explored or even non-existent scenarios before this new experimentation. In short, the concept of smart cities brings Administrative Law closer to the universe of public policies" (all translations to authors are our own). She believes that a technocratic vision is being imposed in this area, based on the consideration that policies based on up-to-date data are more intelligent and that the city is a space that can be managed in real time through the use of ICT and cloud computing. We share, however, her opinion that "This technocratic vision cannot obscure the importance of citizens' rights in this environment and, precisely, the role of Administrative Law and its institutions and categories plays a central role in protecting and guaranteeing them".

Taking the case of Spain as an example, in addition to the legal aspects, there is a need for the homogenisation or at least the interoperability or compatibility of the smart city projects, since the first experiences suffered from the heterogeneity and insufficient dimension of the projects[25]. It is therefore essential that standardisation, and in this sense in Spain, the initiatives in the field of the smart cities must comply with the standards developed by the Technical Committee for Standardisation of AENOR-AEN/CTN 178[26] "Ciudades Inteligentes" (smart cities). This Committee has approved by now more than 30 technical standards for the standardisation of five areas related to smart cities: infrastructure, indicators and semantics, governance and mobility, and energy and the environment[27].

The public-private collaboration is evident in this area, since the leadership of the CTN 178 Committee is based on public initiative but the Committee itself is part of UNE, a privately based association. On the other hand, the technical standards of standardisation approved by the Committee are a source of soft law, in the absence of express regulatory standards for smart city projects. It should be remembered here that the standardisation rules approved by the UNE Committees are voluntary, although in certain areas sectorial legislation or public administrations may require compliance (in

[25] AENOR (2015: 3). AENOR CTN-178 report "Spanish standardization on smart cities". Available at: https://portal.aenormas.aenor.com/descargasweb/normas/aenor-Spanish-standardization-on-Smart-Cities-CTN-178.pdf

[26] It was created in 2012 by the then State Secretariat for Telecommunications and the Information Society (SETSI). The Committee was created within the Spanish Association for Standardization and Certification AENOR, whose activity has now been taken over by the Spanish Association for Standardization, UNE, a private entity with an associative base. The 300 experts who are part of the CTN Committee, belonging to the different Public Administrations involved, to the industry of this sector and to public and private associations representing different interests, are grouped into 25 working groups belonging to five sub-committees responsible for standardisation in each of the thematic areas analysed.

[27] See the UNE website. Committee CTN 178- Ciudades Inteligentes (Smart Cities): https://www.une.org/encuentra-tu-norma/comites-tecnicos-de-normalizacion/comite?c=CTN%20178

public procurement, p.ej.). In this sense, collaboration between the public and the private sector in the development of smart cities is chosen as the best way to advance in this area instead of chosing an strict regulation from the public sector.

## Methodology

Our methodology will consist of the analysis of the legal implications of smart cities, confronting the existing regulation in the European Union on personal data protection and its effectiveness in relation to the use of emerging technologies such as Big Data, necessary for the operation of such smart cities.

## Discussion

The development of smart cities can have a number of legal implications that are important to consider:

a) Big data and Artificial Intelligence techniques and personal data protection regulations (see below)

b) The regulations on e-administration. In this sense, we must take into account that currently the use of electronic means is the main instrument for the management of data and information by Public Administrations, with paper and "physical" procedures being increasingly relegated. The current situation of teleworking and de facto closure of the physical headquarters of the Public Administrations caused by the state of alarm and confinement declared as a result of the covid19 virus pandemic, accentuates and accelerates the importance and progress of e-Administration.

The process has difficulties and has revealed serious errors in its operation and development. However, once the required technological means have been implemented, it will be possible to gain immediate and automated access to the data generated in relation to any procedure carried out by a citizen with the Public Administrations, always in compliance with data protection regulations. The information thus generated must respect the standards established to facilitate its reuse and the storage and management systems must be interoperable as a fundamental basis for the proper functioning and progress of smart cities.

c) Transparency: smart cities need provisions on transparency and access to public sector information. Information and data cannot be reused (a necessity in smart cities), if they cannot be accessed. Transparency regulations and the right to access public information are the basis and guarantee of access to the data needed by the smart city.

(d) Re-use of data/information: smart city projects need rules that allows the re-use of public sector information. The data needs to be open and reusable. The problem in countries such as Spain is that while municipalities can impose data openness obligations on their instrumental entities and on the companies awarded contracts through the technical prescriptions of the contracts, they cannot do the same with the private actors involved in the smart city projects, mainly technology and consulting

companies. In this sense, VALERO TORRIJOS (2017) believes that in specific issues such as compliance with reuse standards or open data obligations, it would be necessary to broaden the subjective scope of the administrative regulations either by modifying them directly or by extending them through contractual clauses on public procurement. This should be done when there is a legal relationship between the municipal administration and the private subjects in the samrt city. When this is not the case, collaboration formulas or other open government techniques should be used to favour accessibility or the transfer of data for its processing by third parties.

e) Citizen participation[28]: smart cities are based on data, from which the city is managed by making decisions with Big Data and Artificial Intelligence techniques based on algorithms. There are numerous ethical, legal and political problems derived from the creation and use of these algorithms. It is important that the principle of transparency is also extended to the algorithms, and that there is no blind trust in them because of their "scientific basis", since they are programmed by people who may have biases (of discrimination by race, ethnicity, sexual condition, etc.) that even they do not know and that may end up being transferred to the algorithm. It is essential that citizens not only have access to public data, but also that they can participate in and have access to the design and control of the algorithms on the basis of which, for example, profiles of citizens themselves are developed and decisions made based on those profiles. In this respect, Article 22 of Regulation (EU) of the European Parliament and of the Council of 27 April 2016 on the protection of individuals with regard to the processing of personal data and on the free movement of such data and repealing Directive 95/46/EC (General Data Protection Regulation or GDPR hereinafter), under the heading of 'Automated individual decisions, including profiling', prevents decisions with legal effects or similar effects on individuals from being taken in an automated manner on the basis of profiles and without human intervention, by providing that "1. The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her".

We see that one of the legal implications that causes most concern in terms of smart cities is related to the privacy of citizens, who may see their privacy or the protection of their most personal or family sphere diminished by the control that cities can make over their data for the proper development of that smart citiy.

One case which in my opinion clearly violates citizens' rights to privacy, personal liberty, personal data protection and non-discrimination is China's 'social credit system', which is already in place[29]. This system gives a score to each citizen according to their civic

[28] In this section we refer to the interesting reflections of VELASCO RICO (2019), *cit.*

[29] These punishments are already taking place in practice. For example, 12 million Chinese have already been banned from buying domestic air and train tickets. The problem is that, although the punishments and reprisals are known, the functioning of the algorithm that determines the position of an individual in the social scale is uncertain, adding to the problem of the violation of rights legal insecurity for citizens and showing how ICT can be used, like any human tool, in

habits, their lifestyle, the websites they surf, what they buy on the internet and other variables such as their traffic offences. The score obtained marks the position of citizens in the country's social scale so that those with high credit will be entitled to preferential treatment by the Administration. On the other hand, those with a low score, face reprisals such as the impossibility to access certain jobs, the prohibition to buy train or plane tickets, to stay in the best hotels, to have their children go to a good school or even to have their pets taken away by the state, all this in addition to be included on public blacklists of bad citizens. China's social credit system is made possible by the combination and integration of various technologies of Big Data, facial recognition and internet monitoring in an environment whose freedoms are not comparable to those of a Western democracy and with the help of more than 600,000 surveillance cameras with artificial intelligence.

A smart city works through mobile applications that, developed by the public body that manages it, allow users to share information about the city they live in so that this information is transformed into useful data that allows better and more personalized development of public services, savings in certain costs or the implementation of certain functions or facilities for citizens, as we have already highlighted. Likewise, many cities implement public wi-fi networks so that citizens can register beforehand and connect through them, being able to know the public entities through them, issues such as the exact location of each user, the means of transport they use or the websites they visit, among others, which constitutes information of great value for these public entities.

This reality shows that the progress of an intelligent city cannot be understood without the collection of millions of data from its inhabitants. Although in many cases these data are processed by the corresponding public administrations in an aggregate or dissociated manner, in such a way that it is not possible to identify the specific citizen to whom the data belong (e.g., with the identification of patterns related to age, sex or marital status), the truth is that in many other cases it would be possible for the public bodies acting behind these connected cities to identify the users who interact with them, through reidentification or inference.

It is clear that if the appropriate safeguards are not in place, the development of the smart city could result in disproportionate interference with the privacy and intimacy of its citizens. Such guarantees, among other issues, would include requesting, from citizens who access (voluntarily) the connected services provided by the smart city, only those data strictly necessary for the provision of the service or specific functionality, without collecting in any case data that may be disproportionate or excessive for the purpose. In this sense, the above-mentioned "join, boos, sustain" Declaration of the EU

an ambivalent way providing freedom and improvements in people's daily lives or the opposite. See OLLERO, Daniel J. (2018); see also DUBOIS DE PRISQUE, E. (2020).

includes a section on "Ethical snd Socially Responsible Access, Use, Sharing and Management of Data"[30].

Furthermore, citizens must be clearly informed, among other things, of what their data will be processed for, who will do it and for how long. And the use of individualised data should be avoided as far as possible: this is achieved by means of anonymisation and pseudonymisation techniques, only aggregated data that do not allow direct identification of citizens should be used.

## Analysis

Smart Cities, Big Data and the Fundamental Rights of City-dwellers

Talking about smart cities without talking about Big Data would be meaningless. Big data can be defined as "large amounts of digitized data that are controlled by companies, public authorities and other large organizations that have the technology to perform extensive analysis of them based on the use of algorithms"[31]. The term Big data refers to a massive accumulation of data that exceeds the capacity of traditional tools to capture, manage and process it in a reasonable time (BALDOMINOS GÓMEZ, MOCHÓN MORCILLO, NAVAS DELGADO, et. al., 2016). A data set is considered to fall into the category of Big data if it requires specialized analysts because it is too large to be handled properly with conventional software programs available to the general public. The approach to collecting, analysing, processing and displaying massive amounts of data, not necessarily structured, for decision making is quite recent, but is becoming increasingly relevant and has enormous potential, thanks to the massive accumulation of data favoured by the widespread implementation of ICT. The essence of Big Data lies in the use of data to solve problems, whether in the business, personal or public administration fields, which gives it enormous potential in the field of smart cities.

[30] The Declaration says that "This data must be used responsibly and its quality, security and privacy ensured by design, to ensure public trust. Practices to be avoided include misuse of data — including unauthorised data sharing, reselling customer data, and biased algorithms that reinforce social inequalities. Digital data must be used in the public interest to improve decision making and public services. Local governments must support practices and initiatives that ensure a better use and management of data, including the once-only and privacy-by-design principles, algorithm transparency and the use of unbiased algorithms to improve quality of life and digital rights in cities and communities." See EUROCITIES principles on citizen data (http://nws.eurocities.eu/MediaShell/media/EUROCITIES_citizen_data_principles_ final.pdf) and the Cities Coalition for Digital Rights (https://citiesfordigitalrights.org).

[31] Definition of the International Working Group on Data Protection in Telecommunications: IWGDPT (Berlin Telecommunications Group). According to ÁLVAREZ HERNANDO (2010), the Berlin Group was established in 1983, within the framework of the International Conference on Data Protection and Privacy in the initiative of the Berlin High Commissioner for Data Protection, at the initiative of the data protection authority of the Länder of Berlin, where it has its headquarters. It brings together, together with representatives of the supervisory authorities of a large number of States, representatives of public and private international organisations, and representatives of the industrial sectors involved. In short, it is an open working forum that seeks to debate the implications of the use of telecommunications in the private sphere of individuals and in the protection of their personal data, trying to anticipate the problems that arise in practice. The Spanish Data Protection Agency regularly participates in the activities of this group, which meets every six months in different countries of the world. The Group also issues opinions and working documents.

Among the common characteristics of the Big Data, independently of the sector we are talking about, we find among them, besides the variety, volume and speed ("the 3 v's"), a fourth "v", the veracity, to which a fifth "v" is normally added, referring to the valorization (ISHWARAPPA and ANURADHA, 2015). The latter is fundamental and consists of identifying, in the case of smart cities, how the municipal government can analyse the data and draw conclusions in order to carry out actions such as predicting the behaviour of public service users, identifying tastes or needs by user groups or segmentation and their subsequent application to the provision of the services[32].

In short, the Big Data or Macrodata involves the collection of massive amounts of data by public or private organizations that, through the use of technological tools of Artificial Intelligence and Automatic Learning (Machine Learning) based on algorithms, are able to analyze such data in order to obtain information that can be very valuable and profitable. And that is why Big Data is closely linked to smart cities and IoT (Internet of Things), as well as to privacy and personal data protection, provided that their use involves the processing of such data.

The European Union's establishes certain data protection principles that are mandatory for all smart city projects. Among others, the principle of data minimization stands out, which implies that the information collected and processed will be the minimum essential to meet the pursued purpose, the obligation of pseudonymization or the principle of privacy from the design. Projects carried out on the basis of anonymised data will not be obliged to respect this regulation, since as the GDPR points out in Recital 26 " The principles of data protection should therefore not apply to anonymous information, namely information which does not relate to an identified or identifiable natural person or to personal data rendered anonymous in such a manner that the data subject is not or no longer identifiable".

In this regard, and in order to determine whether there is processing of personal data and use of Big Data techniques in smart cities, it would be necessary to establish firstly whether the information collected is going to be processed (the answer is logically positive, as it will be used and processed to design, improve and provide services to citizens) and secondly, whether or not this information makes the final users involved identifiable. As the data protection regulations rightly point out, there are techniques that make it possible to reduce the risks inherent in the maximum processing of personal data, such as anonymisation and pseudonymisation. However, these techniques should not be confused: while anonymization allows the specific person to be unidentifiable, since the link with the personal data is completely dissociated, pseudonymization does not eliminate this link with the person's data, but rather assigns the user a series of data that do not a priori make him or her identifiable but which, in connection with other data, would allow them to be associated with a specific user.

[32] On this issue, please refer to DURÁN RUIZ (2018).

In particular, what must be borne in mind in relation to the use of Big Data techniques in smart cities is the need to use certain techniques that allow massive data processing to be carried out in a responsible and secure manner, in order to protect the rights and freedoms of the users themselves at all times, who could see their data or personal information being marketed by third party companies for their own benefit, trying to avoid as far as possible for the information collected to be directly identified with each end user. This is why it would be highly recommendable to use anonymisation or, where appropriate, pseudonymisation techniques, which make it impossible to identify the end user of the smart city services and which ensure that the information is only processed in an aggregate and dissociated manner.

Prior to the implementation of a smart city project, in relation to the protection of personal data, an analysis of several issues must be carried out, as provided for in Section 3 Chapter 4 GDPR on 'Data protection impact assessment and prior consultation': (1) the volume of information subject to processing, (2) the number and type of sources to be used to obtain the data or information, and (3) the time of conservation of such information (Article 35 GDPR).

This prior assessment shall include at least a) a systematic description of the envisaged processing operations and the purposes of the processing, including, where applicable, the legitimate interest pursued by the controller; b) an assessment of the necessity and proportionality of the processing operations in relation to the purposes; c) an assessment of the risks to the rights and freedoms of data subjects referred to in paragraph 1; and d) the measures envisaged to address the risks, including safeguards, security measures and mechanisms to ensure the protection of personal data and to demonstrate compliance with this Regulation taking into account the rights and legitimate interests of data subjects and other persons concerned (art. 35.7 GDPR).

In addition, the Data Protection Authority should be consulted, according to Article 36.1 GDPR which provides that the controller "shall consult the supervisory authority prior to processing where a data protection impact assessment under article 35 indicates that the processing would result in a high risk in the absence of measures taken by the controller to mitigate the risk".

Another consideration prior to the development of smart cities projects is the prior consent of the persons concerned for the collection and processing of data. In this respect, it is important to remember that, as a general rule, Public Administrations do not need the consent of the data owners when they collect the data for the exercise of their own competences, as long as its use is lawful and in accordance with the law and the data to be used is provided. This is a prerogative of the administrations in the generality of the countries of the EU that cannot be applied in a direct way to the operations of commercial exploitation of the personal information, since in this case it is incompatible with the purpose that in principle justified its collection and treatment,

although the access to the same ones is considered necessary to be able to develop the concrete project.

In the smart cities, the data processing operations carried out are not simple transfers of data, but rather generalised interconnections between different actors whose fundamental characteristics are their massive and automated nature. As in the smart cities diverse services are integrated and there is a horizontal and not vertical management of the same, which goes beyond each of the services considered separately, this directly affects the principle of quality of the data, according to which the same could not be used for other purposes incompatible with those that justified their collection.

With the exception of what has been said with respect to the data collected and processed by the Public Administrations for the exercise of their powers, the entire system for the protection of personal data is based on the idea that the processing of personal data requires the prior and unequivocal consent of the interested party or owner of the data, since this principle allows the person to exercise effective control over the use of his or her data by third parties. This translates into the requirements set out in the GDPR for the consent of the interested party to allow the processing of his or her personal data: that it be free, specific, informed and unequivocal, and that it be done either by means of a declaration or by means of a clear affirmative action, never in an implicit or supposed manner. Thus, the General Regulations define "consent" of the data subject" (art. 4.11) as "any freely given, specific, informed and unambiguous indication of the data subject's wishes by which he or she, by a statement or by a clear affirmative action, signifies agreement to the processing of personal data relating to him or her"[33].

The GDPR has therefore tightened the requirements for the consent given to be considered valid. Tacit consent is no longer valid, and not only that, when data processing has several different purposes, consent must be given for each and every one of them.
Consent, as WG 29[34] has rightly stressed, if properly used, "is a tool which gives the subject control over the processing of his data. If it is used incorrectly, the control of the subject becomes illusory and consent then constitutes an inappropriate basis for the processing of the data".

The inadequacy of privacy policies and the provision of user consent to such policies has become apparent in recent times, considering that the vast majority of users do not even read the terms of privacy policies or if they do read them they do not understand them.

[33] The specific nature of consent "indicates that the consent must relate to a specific processing operation and to a specific, explicit and legitimate purpose of the controller. Its informed nature implies, as we have mentioned, that the data subject is aware of its existence and the purposes for which it is being processed prior to the processing. Finally, the consent must be unequivocal, so that it cannot be deduced tacitly or presumably from the simple acts carried out by the data subject, and it is necessary that there be an express act or omission that implies the existence of consent" (DURÁN RUIZ, 2015).
[34] Article 29 Working Group (2011, 2014), Opinion 06/2014 on the notion of legitimate interests of the data controller under Article 7 of Directive 95/46/EC (2014); Opinion 15/2011 on the definition of consent (2011).

For this reason, with the implementation of the principle of transparency, which is set out in article 12 GDPR and plays an important role, the need has been incorporated for a different wording of the privacy policies, which guarantees effective notification, and for the development of mechanisms that allow truly informed consent to be given.

With the introduction of new information technologies such as Big Data, consent is clearly insufficient in itself for the protection of personal data, and it is questionable whether it is truly informed consent and also the principle of data quality, since the data is clearly used for purposes other than those for which it was obtained, as can easily happen in smart city projects. However, as we have stated, the data can be used if, due to anonymisation, they are no longer considered personal data and therefore not subject to data protection regulations (Recital 30 GDPR).

Although solutions have been put forward to the wording of the information to ensure that the consent of users is truly informed consent. We reiterate here that "The operation of new ICTs such as Big Data makes this task extremely difficult, since data move from one place to another, from one recipient to another in an unpredictable manner, and especially because the value that the data may have is not known and cannot be known at the time they are collected, making consent an 'all-inclusive' and distorting or violating other essential principles of data protection such as data quality (DURÁN RUIZ, 2019).

In this sense and in relation to this technology, GIL GONZÁLEZ (2016) points out that "the chain of data senders and receivers is potentially infinite, and includes actors and institutions whose role and responsibilities are not delimited or understood. Thus, the transfer of data can become relatively obscure". It raises the question of whether the obligation of the data controller to inform about the collection of data is limited to the information he explicitly collects, or whether a broader criterion should be adopted and it should be understood that this duty of information also extends to that information that the institution may obtain after processing, as may be the case if the information is reused or transferred for processing by means of Big Data by third parties from data collected by the municipal administration in an smart city.

The majority doctrine is of the opinion that the consent and information provided to the person giving it must also refer to the information that can be extracted from a sophisticated analysis of the personal data, including the information that can be extracted by aggregating that data with other files and sources, and not only to the fact that primary data is collected. However, in practice, because of the very characteristics and nature of technologies such as Big Data, where it is not possible to predict the results or relationships that will be obtained from the data, this solution seems impractical. If the data controller himself cannot know in advance what use, application or results the data obtained will yield, the user cannot be informed in advance of the purpose for which the data are being collected. As GIL GONZÁLEZ (2017) states, "a new difficulty has arisen

from the fact that the greatest value of information no longer lies in its primary use, but now lies in its secondary uses, and this affects the core of personal data protection".

This has led experts (GIL GONZÁLEZ, 2017; DURAN RUIZ, 2018b), to suggest that attention cannot be so focused on the moment of giving consent for the processing of data and on the systems for giving true informed consent, but that it must be moved to the moment of actual use of the data, and this must be done in the data collected for processing in the smart cities.

## Conclusions

The tendency to concentrate the population in cities makes it essential to have mechanisms and technologies that guarantee the sustainability of urban developments, respect for the environment, the rational use of available resources and the adequate treatment of the waste generated. It is therefore essential to make a decisive and global commitment to smart cities, in order to improve the provision of public services and to face the challenges that, in the medium term, must be faced at world level in the management of urban spaces.

The European Union is trying to be a world reference in smart city projects, and to promote them, firstly is funding initiatives and projects in this field, and secondly is playing the role of harmonising or coordinating the legislation of the Member States and technical standards in order to make this reality. Only with the intervention of the EU will it be possible to create a homogeneous legal and technological framework that will provide a standardised model of smart city throughout its territory. The most direct benefit of this policy is that it creates a large internal market that increases the EU's business attractiveness and this is what the Digital Single Market is aimed at as a parallel EU initiative. The European Reference Framework for the Sustainable City (RFSC) is an example of this initiative.

The legal implications of the implementation of smart cities in the EU are numerous, affecting the regulations on e-government, transparency and the right to access public information, citizen participation and personal data protection. It is clear that if the appropriate guarantees are not fulfilled, the development of smart cities could mean an excessive interference in the privacy and intimacy of its citizens and a form of social control by the Administration, as in the case of China.

Before an smart city project is developed, in relation to the protection of personal data, it must be carried out, as provided for in Section 3 of Chapter 4 of the GDPR on "Data protection impact assessment and prior consultation". In compliance with the GDPR, the development of smart cities projects must be based on the prior consent of the persons concerned for the collection and processing of the data, although, as a general rule, the Public Administrations do not need the consent of the data owners when they collect them for the exercise of their own competences, as long as their use is lawful and in accordance with the law and the data to be used are provided. However, this prerogative

has limits and cannot be directly applied to the operations of commercial exploitation of personal information. The nature and operation of Big Data techniques applied to the personal data of citizens that are collected and processed in a smart city, cause the consent as the basis of the treatment to lose sense and therefore it is necessary to change this paradigm, moving the consent to the moment of actual use of the data.

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# Teaching and Learning through Laboratory Experiments in the Area of Nuclear Technology

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## Abstract

Simulated laboratories are an effective tool to complement teaching and learning processes, in this case, in the area of nuclear physics and related sciences. They can be used in universities, schools, and research centers for personnel ramp up and training. This work presents the development of a simulator of a nuclear radiation counter and the elements used in experiments alongside it, such as simulated radioactive sources, absorbing materials and dispersing materials of radiation. This simulator allows us to verify the scientific laws that are involved in the interaction of radiation with matter, in a safe and reproducible way. The simulated laboratory experiments include determining the plateau curve of a Geiger-Müller tube, beta particle absorption and backscattering, and radioactive background. The data obtained from the simulations is based on the real experiments, eliminating the inherent risks of the manipulation of radioactive materials. This also allows to verify theoretical concepts in practice, strengthening the learning process and incentivizing research, interpretation,

integration and communication of the obtained results. By incorporating this simulator in the multidisciplinary teaching and learning processes in STEM fields, it is possible to run these laboratories in a simple manner using non-radioactive materials.

**Keywords:** teaching, learning, technology, experimentation, simulator, nuclear, simulated education

## Introduction

Laboratory experimentation on Science, Technology, Engineering and Mathematics (STEM) subjects allows students, professors and professionals to apply interdisciplinary concepts where the theoretical aspects of scientific developments can be applied to a real-life activity. In these experiments, schools, scientific communities and the industry come together as a cohesive unit.

At the same time, the usage of simulators in teaching and personnel training is becoming wider in all stages of academic and/or professional career developments, especially on fields where the experiments are either complex, expensive or dangerous. Simulating these experiments transforms them into simple, cost-effective and safe experiments, through the use of the data obtained from real experiments. By doing this, the student can qualitatively and quantitatively verify the scientific laws that interact with the real world, in an environment with the aforementioned benefits (Perez Lucero et al., 2015).

Nuclear physics, in particular, is one of those fields. Most of the experiments involve the manipulation of radioactive material, which means that experiments must be done on nuclear laboratories with the proper protection to use them. This poses an accessibility problem for schools and universities who do not have a nuclear laboratory and want to teach about Nuclear Physics, as they would be unable to provide a valuable laboratory experimentation for their students.

In the upcoming sections, we present a project of a Geiger counter simulator, as a part of a broader project (Chautemps et al., 2019). This simulator puts the user in a similar environment as the real experiment environment, where the user can develop skills, learn operative procedures, and reinforce knowledge of theoretical and practical aspects from the real experiments. All of the simulations can be done an unlimited number of times, which also allows to adjust to the user's own learning process. The simulator presented in this work is the second iteration of said project, adding data for an additional experiment, and updating the user interface in order to simplify future upgrades, and extend the lifespan of the simulator.

## Background

Geiger counters are instruments used for detecting and measuring ionizing radiation. They consist of a Geiger-Müller tube, a cylinder filled with ionizing gas, and electrical components that count the amount of ionizing pulses that come from inside the tube. A basic scheme of the Geiger counter can be seen on figure 1.

Whenever a charged particle (such as $\alpha$ or $\beta$ particles) goes into the detector, the gas gets ionized. This produces a chain reaction that lasts for a fraction of a second which, in turn, produces a pulse, which is processed by the pulse counter. The pulse occurs due to the power supply, as it forces electrons to accumulate on the anode, and positive ions on the cathode.

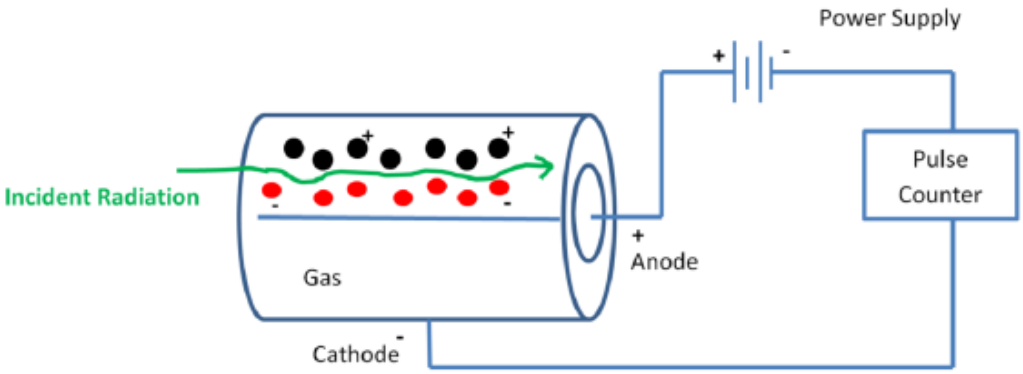


Figure 1: Geiger Counter Scheme

## Simulator description

This section explains in detail the different laboratory experiments and how the user should operate the simulator in order to obtain the results from each experiment. The simulated elements include the electrical supply voltages of the Geiger counter, radioactive sources, absorbent elements and particle dispersers. These values are used to determine the Plateau curve of the aforementioned instrument, the values of the absorption and backscattering of charged particles by different materials exposed to the selected radioactive source, and the effects of background radiation.

This iteration of the simulator adds the capabilities for all measured data to variate according to known statistical distributions for each piece of data, unlike its predecessor which has fixed values for all data types (Lazarte et al., 2016). This variation of data allows the simulator to resemble the real experiment more closely, as there is always some degree of error and variation when measuring in the real-life experiment.

Laboratory 1: Determining the plateau curve of the Geiger Counter

The plateau curve indicates the appropriate supply voltage for a Geiger counter. If the voltage is too low, radioactive activity will not be equally distributed along the cathode; if the voltage is too high, the tube may be damaged by the continuous discharges. An appropriate supply voltage will be in a zone from the curve in which the amount of counts per minute grows linearly when increasing voltage, with the optimal point being in the middle of this zone, to reduce the effect of variations in the voltage (Knoll, 2000). The graph shown in figure 2 shows a graphical representation of the plateau curve.

In order to experimentally obtain the aforementioned curve, the user would need to vary the supply voltages used on the tube, measuring on every variation the amount of counts per minute returned by the pulse counter. Using this data, the user will be able to plot the curve and graphically determine the optimal supply voltage.

In the simulator, the user is able to select the supply voltage from a set of pre-loaded data on the simulator, which has been obtained from doing the real experiment.

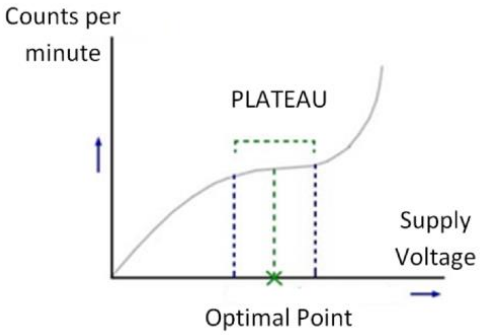


Figure 2: Plateau Curve of the Geiger Counter

Table 1 shows the measured activity (in counts per minute) as a function of the supply voltage of the detector. The values displayed on the simulator are slightly modified following a statistical normal distribution, in the same fashion as in the real experiment.

| V (voltage) | Am – Background (cpm) |
|---|---|
| 550 | 0 |
| 600 | 0 |
| 625 | 0 |
| 650 | 695 |
| 675 | 1537 |
| 700 | 1592.333 |
| 725 | 1557.4 |
| 750 | 1590 |
| 775 | 1626 |

| | |
|---|---|
| 825 | 1759.333 |
| 850 | 2037.666 |

**Table 1: Activity according voltage source**

The simulated elements are shown on figure 3.

**Figure 3: Simulated plateau curve of the Geiger counter**

## Laboratory 2: Absorption

The next laboratory focuses on two aspects of nuclear experimentation: on one hand, determining which radioactive material is acting as the radioactive source (that is, to determine whether the source is Cobalt-60, Sodium-22, Strontium-90, etc.); on the other hand, determining the minimum thickness of an absorbing material so that it can block incoming radiation from the radioactive source. To block incoming radiation, the required material depends on the type of radiation that the user would want to block. $\boldsymbol{\alpha}$ radiation is blocked by paper, $\boldsymbol{\beta}$ radiation by metals and $\gamma$ radiation by concrete and/or lead, as shown in figure 4. This laboratory focuses on blocking $\boldsymbol{\beta}$ radiation.

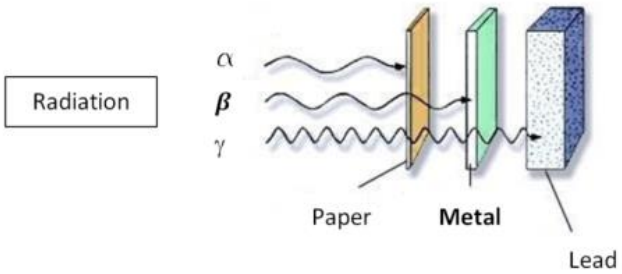


Figure 4: Radiation types and blocking materiales

In order to obtain the minimum thickness of the radiation-absorbing metals, the student will have the superficial density of the piece of metal, and the density of the metal, which is always constant. Using these data, it is possible to obtain experimentally the thickness of the absorbing metal.

On a real experiment (as shown on figure 5), the required elements include a $\boldsymbol{\beta}$ particle source, absorbers of various thicknesses, and a Geiger counter (Parks, 2001).

Figure 5: Real absorption experiment setup

The simulated elements are shown on figure 6. The simulator returns activity count values corresponding to the radioactive source and the thickness and type of the absorbing material being simulated, with the radioactive source being on the third slot of the tower, and the absorbing material being on the second slot. The data obtained will be a value based on the results of a real experiment shown on table 2.

Figure 6: Simulated absorption experiment setup

The user of the simulator should take note of the activity count values displayed by the simulator. These values can then be plotted and, through and approximation technique (on most cases, minimum squares), it is possible to obtain an exponential fit to the obtained data. An example of this curve is shown on figure 7. The fit of the curve will be of the form $\boldsymbol{y = a\, e^{-bx}}$, where the absorption coefficient can be calculated by obtaining the value of b (Martinez Alonso & Losada Ucha, 2000).

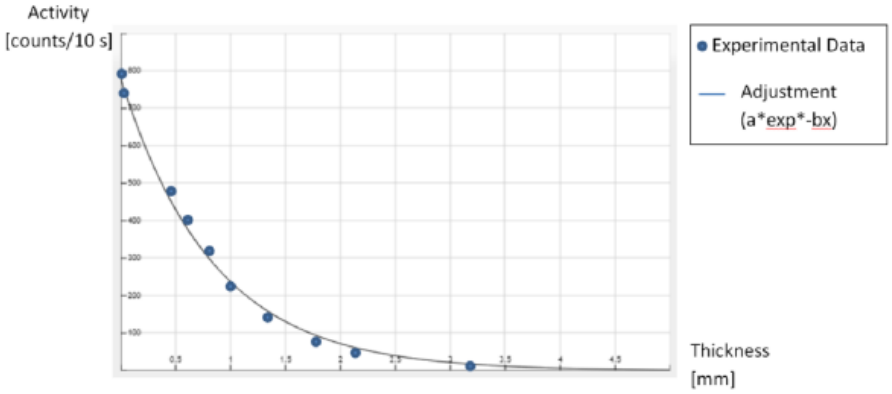


Figure 7: Simulated absorption experiment curve fitting

The next step on the experiment is to obtain the maximum energy before $\beta$-decay. This can be done using the thickness of the material that resulted in the lowest amount of counts per second, and then mathematically obtaining the maximum energy with this data.

Finally, comparing the maximum energy with known $\beta$-decay patterns (as shown on figure 8 (Knoll, 2000)), the user can determine the radioactive being used.

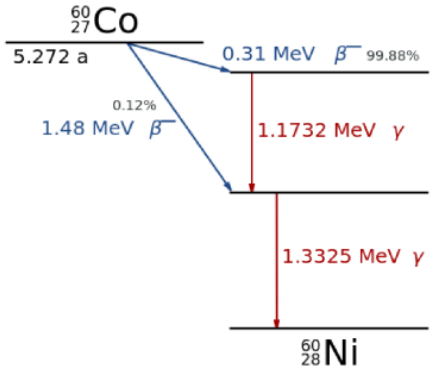


**Figure 8: b-decay of Cobalt-60**

| Co-60 Source | |
|---|---|
| Absorbent material | Measured activity (cpm) |
| Without absorbent | 2861 |
| Paper | 2632,12 |
| 45 mg/cm² | 1773,82 |
| 290 mg/cm² | 572,2 |
| 1100 mg/cm² | 28,61 |

| Na-22 Source | |
|---|---|
| Absorbent material | Measured activity (cpm) |
| Without absorbent | 16962 |
| Paper | 15605,04 |
| 45 mg/cm² | 10516,44 |
| 290 mg/cm² | 3392,4 |
| 1100 mg/cm² | 169,62 |

Table 2: Activities from radiactive sources

### Laboratory 3: Backscattering

This laboratory experiment analyzes the radiation from the radioactive source when the incident $\beta$ radiation scatters when going through different materials. This experiment shows that the materials used as scattering materials exhibit this behavior, and that the scattering effect is more prominent on materials with a higher atomic number.

When a $\beta$ particle coming from a radioactive source interacts with a material, its trajectory may deviate depending on its initial energy. This produces a dispersion effect on the particle. Depending on the relative orientation of the impact between the $\beta$ particle and the core of the material's atoms, there is a chance that the $\beta$ particle exits the material on the same spot where it entered the material. This phenomenon is called backscattering.

In this experiment, the user first measures the radiation activity count when there is no scattering material in between. After that, the user adds different materials at the end of the source and measures the activity count once again. The difference between the two allows to determine which is the scattering material being used. A schematic of the experiment setup is shown figure 9.

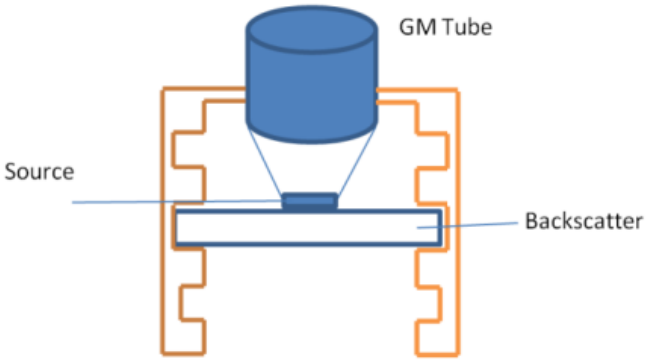


Figure 9: Backscattering experiment schematic setup

In the simulator, the setup is shown in figure 10. The different simulated elements (the radioactive source and the backscattering material) are placed in a tower similar to the one used on the previous experiment. The position of the simulated elements resembles the real experiment.

Figure 10: Backscattering experiment simulated setup

In the practical work of interaction of radiation with matter, for the study of the dispersion of charged particles, the real data shown in table 3 is stored in the simulator.

| Backscatter | Average measured activity (cpm) |
|---|---|
| Without backscatter | 2899,666 |
| Aluminum | 3276,62258 |
| Iron | 3537,59252 |
| Zinc | 3624,5825 |
| Cadmium | 3914,5491 |
| Lead | 4204,5157 |

Table 3: Backscatter

Laboratory 4: Background radiation

This laboratory focuses on the radiation that exists on the environment, without the deliberate introduction of a radioactive source. This radiation is also called background radiation. On a laboratory setting, figure 11, if the objective is to measure the radiation counts of a specific radioactive source, the Geiger counter will inevitably count the background radiation, the latter should be measured beforehand to appropriately subtract the background component from the measurement.

This laboratory is an expansion made to the previous iteration of the simulator, which did not have this experiment implemented (Lazarte et al., 2016).

The experiment consists in measuring the amount of counts measured by the Geiger counter over a short period of time, without any radioactive source nearby to prevent noisy data (Mera, 2015). This measurement should be done a number of times. Based on a real experiment (Suárez, n.d.), the simulated experiment simulates a measurement every 2 seconds, doing this a total of 100 times. The measured counts can be plotted in a histogram, which should resemble a Poisson distribution frequency histogram, with parameter $\lambda$ =1.06 as the average amount of counts every 2 seconds, as shown on figure 12. A table 4 with the measured counts and the histogram of it are plotted on the display.

Figure 11: Setup for background radiation measurement

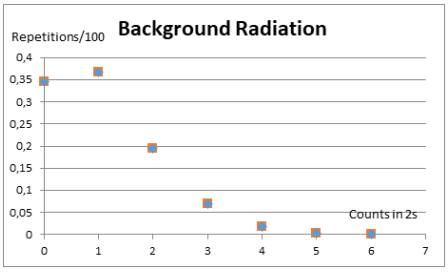


Figure 12: Background radiation

| Conts/100 | Value |
|---|---|
| 0 | 0,346 |
| 1 | 0,367 |
| 2 | 0,195 |
| 3 | 0,069 |

| | |
|---|---|
| 4 | 0,018 |
| 5 | 0,004 |

Table 4: Radiation counts/100 values

## Validation and results

The improvements made on the simulator for this iteration were developed during the COVID-19 pandemic.

As on-site lectures and laboratory work went virtual, the changes were not able to be validated with students. For this reason, this section will be based on the results obtained with the previous iteration of this simulator; which was used on late 2019, on a course of "Methodology and Application of Radionuclides", taught by the University Center for Nuclear Technology (CUTeN), of Faculty of Exact, Physical and Natural Sciences, part of the National University of Cordoba, Argentina.

The course consisted of 30 students, where as part of the laboratory practice exercises, they used the presented simulator. At the end of the corresponding exercises, the students were asked to answer a survey that focuses on the effectiveness and the overall reception of the simulator and the experiments conducted with it.

The table 5 indicates the questions asked to the students on the survey, and the figure 13 and figure 14 indicate the results obtained from the survey. The first two questions refer to information about similarity to the real experiments and understanding the real phenomena; the other three questions ask the user to rate the degree of learning that they have achieved of various concepts taught with the help of the simulator.

The results from the survey indicate that students perceived positive effects on the learning process of different topics related to the usage on the simulator, and they also showed a high degree of acceptance of the tool.

| Question | Options |
|---|---|
| Q1: The simulator is similar to its real counterpart | Greatly agree,<br>Agree,<br>Slightly agree,<br>Do not agree |
| Q2: Using the simulator helped me understand the physical phenomena | |
| Q3: Rate your learning achievement of the working mechanisms of the instruments | Achieved,<br>Partially achieved,<br>Not achieved |
| Q4: Rate your learning achievement of radioprotection (distance-time-protection) | |
| Q5: Rate your learning achievement of the behavior of radionuclides (decay, half-life period) | |

Table 5: Questions and possible answers asked on the survey

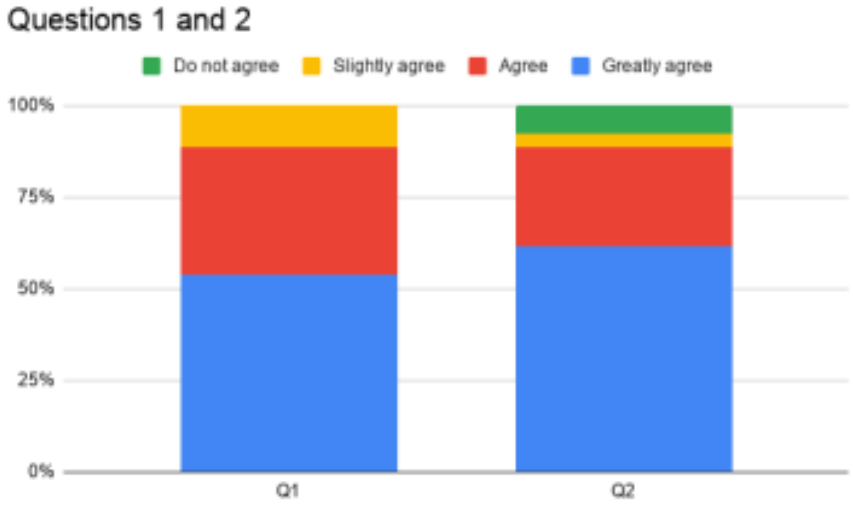


Figure 13: Answers to Questions 1 and 2

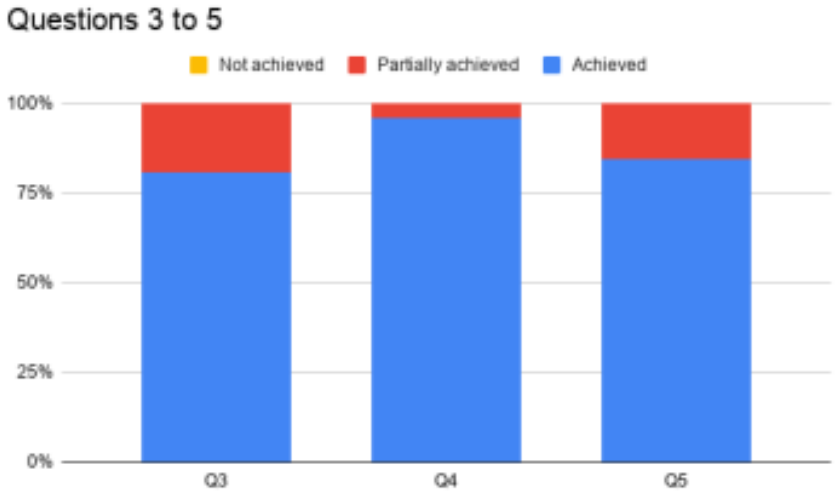


Figure 14: Answers to Questions 3 to 5

**Future work**

This simulator is part of a broader project. As part of the scope of the extended project, it is planned, in the near future, to upgrade the prototype of the simulator to allow usage both physically and remotely through the internet. The implementation done in this iteration can, in the future, be extended more easily than in the previous iteration to enable remote usage.

Another feature under consideration is to add new tables for the radioactive activity values for other radioactive sources, absorbent materials and dispersers.

Finally, adding new simulations for other experiments not implemented already is also under consideration.

## Conclusion

The simulator presented in this article has as its main objective to improve laboratory activities on schools, universities and laboratories. Laboratory experiments develop students' skills in dealing with laboratory instruments and physical processes with the objective of reinforcing the understanding of the investigated subject (Malkawia & Al-Araidahb, 2013).

This prototype of a simulator of a nuclear radiation counter was designed and built having as main purpose allowing to obtain real data using simulated elements. This simulator has four modes related to real-life experiments: obtaining the plateau curve that shows the basic behavior of a Geiger counter; obtaining curves that show the radioactive activity in relation to the thickness of the absorption materials which can, in turn, be used to estimate the energy of the particle-emitting source; evaluating the behaviour of radiation as it goes through dispersers; and finally, measuring the background radiation of an environment.

As the radioactive activity data provided by the simulator is based on real experiment, the usage of this simulator allows to manipulate radioactive sources, absorbing materials and particle dispersers in a safe, simulated environment that resembles the real world experiments.

This simulator is the second iteration of a broader project. This part adds usage through a touchscreen that, even though the interface deviates from actual instruments due to the lack of buttons, it makes the simulator more durable and does not compromise the validity of the data. In addition, this simulator adds the capabilities to return data based on statistical parameters in order to more closely resemble an actual experiment. Finally, this simulator is easier to extend in the future for remote usage.

The remote experiments will be introduced to students gradually in three planned phases: in the first phase, in preparation for a typical remote laboratory experiment, the students are tasked with re-familiarizing themselves with the underlying physical principles, the experimental equipment and procedure of the particular experiment to be performed. In the second phase of the laboratory experience, will use the supervision of an instructor and in the third stage, the studends will continue more detailed experimental studies in a remote fashion (Nickerson et al., 2007).

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