Universal Design to Limit Food Cross-Contamination: Incased Set of Kitchen Utensils with Five Color-Coded Food Chopping Boards and Knifes

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Abstract
This study is focused on a conceptual design of a kitchen appliances/utensils set, comprising of five color-coded food-chopping-boards and five matching-color-coded-knifes, to reduce cross-contamination at private homes, as well as at food establishments. Selected relevant Patents, as well as products, available locally and internationally, were analyzed. The Joseph Joseph Index™ Color-Coded Chopping-Boards set (of four), was chosen as a point of reference for the current design; its seven identified limitations have directed the scope of the current design. Target specifications/objectives of the set, were formulated from the document analysis, while Pair-wise Comparison Charts were used, to rank the importance of the objectives, in the different levels. The best ranked design (out of the four alternatives made) was chosen, via standard Engineering Design Weighted Decision Matrix (EDWDM) and ‘Drop and Re-vote’ (D&R) method. 2D drawings, of the best design alternative, were created via computer-aided-design (CAD) AutoCAD software 2018, while 3D modeling, of the set and all its components, was produced by Autodesk Inventor Version: 2016 (Build 200138000, 138). Designed labels (positioned on each-board and each-knife, as well as on the set itself, as an inclined panel) were introduced to cater for the people with color-blindness (according to the fundamental principles of the Universal design), and also to avoid confusion (as a reminder which board is which) for all users. The study adopted ‘analysis’ method of materials selection. The main objectives, of the intended set, was used as a guide, in preliminary materials selection. This concise study has focused on conceptual design only; and hence, it is further recommends to: (i) carry out a detailed design; (ii) select a specific material (out of the group, identified by this study); (iii) choose a mode of fabrication of the set; (iv) examine the possibility of incorporating of anti-microbial-agent(s) and/or coating(s); (v) fabricate the prototype(s); (vi) conduct explorative use-ability-trials; and (vii) analyze the marketing aspect of the final set. This work is potentially beneficial to engineering product design students and faculty, as well as to households and food establishments (subject to successful implementation).

Keywords: Color blindness; Materials selection; Food safety; Joseph Joseph Index™ Color Coded Chopping Boards set.

DOI: 10.7176/ISDE/10-5-05
Publication date: June 30th 2019

1.0. Introduction.

1.1. Food-safety and food-contamination.

1.1.1. Food-safety.

FAO & UN (1999) states, that: “It is important to differentiate between food-safety and food-quality”; Safety refers to hazards to human health-in-food, while Quality refers to all attributes, and thus, might include safety. In particular, Food-safety encompasses actions, aimed at ensuring that all food is as safe as possible (World-Bank, 2000). According to Velusamy et al. (2010), food-safety is a global health goal, while food-borne diseases are a major health issue, worldwide. The latter, in general, can be attributed by several factors, such as: the nature of food and its preparation, under-cooking of the food, dirty equipments and cutting-surfaces, and the food-handlers themselves, among others.

The risks to food-safety, according to the World-Bank report of 2000, fall into four broad categories, namely; (i) microbes, through improper-handling; (ii) parasites, through improper cooking; (iii) physical-agents, which may be intentionally, or accidently, added into the food; and (iv) chemicals, which occur naturally in food, and those, which are present in the environment (World-Bank, 2000).

All countries share similar concerns about food-safety hazards, but the relative importance of risks differs with climate, food-eating and cooking habits, levels of income, and public infrastructure. Some risks are greater in developing countries, due to poor sanitation and inadequate water supplies (World-Bank, 2000).

1.1.2. Food-contamination.

WHO (2008) defines food-contamination as “the introduction or occurrence of a contaminant in food environment which causes food to be unsafe”. WHO (1999) developed a framework, that outlines the various sources of food contaminations, to include: food-handlers, flies and pests, polluted-water, dirty pots and cooking utensils, domestic animals, indigenous micro-flora, infected food, animals, and human excreta. Ball et al. (2013) outlines
the-following-factors to-be the-major-causes of food-contamination: (i) Preparation of food, several-hours prior-
to consumption; (ii) Insufficient-cooking or reheating; (iii) Cross-contamination; and (iv) Serving of food using dirty-utensils.

This-study is focused of the-food-cross-contamination and its-reduction.

According-to WHO (2008), food-contamination-transfer is dependent on the: (i) surface; (ii) food-type (the-moisture of the-food); (iii) contact-time; and (iv) inoculums-matrix. Epidemiological-data indicate that cross-

Figure 1 shows the-simplified model of food-cross-contamination.

![Figure 1: Cross-contamination-channels.](image)

Household, and other-food-establishment-types, have been the-focus of numerous-food-cross-

1.1.3. Food-borne-diseases and their-impacts.

Food-borne-diseases are regarded-as acute-illnesses, associated-with the-recent-consumption of food, having normally a-short-incubation-period, and symptoms, with gastrointestinal-features, including: vomiting, diarrhea, and abdominal-cramps. In-some-cases, there may be neurological and other-symptoms, connected with the-

Although proper-food-handling, preparation, storage, and feeding-practices may prevent many-food-
borne-diseases, each-year, millions of people become ill, and thousands die, from these-diseases (Kumiko et al., 2009). The-Centers for Disease-Control and Prevention (CDC, 2015; 2014) estimates, that each-year there are more-than 9 million-episodes of food-borne-illness, over 55,000 hospitalizations, and at-least 1,351 deaths, that can be attributed-to foods-consumed, in the-United-States (Scallan et al., 2011), while FSWSG (2008) indicates much-higher-fatality of 3,000 people, while WHO (2008) estimates even-higher-number of deaths (5,000), to-occur each-year, in the-U.S.A., alone. In-particular, during 1998-2008 periods, reporting was made, through the-electronic Food-borne-Outbreak-Reporting-System (eFORS), that out of the 7,998 outbreaks, with a-known- etiology, 3,633 (45%) were caused by viruses; 3,613 (45%) - by bacteria; 685 (5%) - by chemical and toxic-agents; and 67 (1%) - by parasites (see Gould et al., 2010 for more-details).

The-Health-Canada and the-Public-Health-Agency of Canada also-estimate that every-year, between 11 and 13 million Canadians suffer from illnesses, caused by food-borne-contamination-agents (FSWSG, 2008). In 2005 there were 1,545 incidents of food-poisonings, reported in-Japan, and 86% of those were caused by bacteria or viruses (WHO, 2014). Besides, Campylobacter jejuni is identified as the-top-five of pathogens, causing most-food-related-infections, worldwide (Zwietering & van Asselt, 2005). In-the-Netherlands, for-instance, there are an-estimated 65, 000 campylobacteriosis-cases, per-year (Kemmeren et al., 2006).

Several-devastating-outbreaks of food-borne-diseases, such-as: salmonellosis, enterohaemorrhagic Escherichia coli (EHEC), cholaera, hepatitis A, and acute-aflatoxixnosis, have occurred in-a-number of African- countries, relatively-recently. For-example, outbreaks of cholaera, in 2004, in 28 countries resulted in 85,807 cases, and 2,221 deaths. In 2005, reports from 30 countries indicated that 33,934 cases were recorded, and 1,161 deaths have occurred. During the 2004, an-outbreak of acute-aflatoxixnosis, in-Kenya, reported 317 cases and 125 deaths. Another-outbreak, reported a-further 74 reported-cases and 28 deaths, in 2005 (FAO & WHO, 2005).

In-Kenya, food-poisoning, or food-borne-illness, is quite-prevalent. A-report by FAO & WHO (2005) indicates, that in 2004, the-following-incidences were observed, in-Kenya: gastroenteritis (722,275 cases), typhoid (643,151 cases), dysentery (600,660 cases), aflatoxin-poisoning (323 cases), brucellosis (198 cases), and cholera (56 cases). One of the-most-devastating water- and food-born-diseases is considered to-be a-cholera, caused by one of the Vibrio cholerae species. Seven-global-pandemics, of this-contagious-disease, have been recorded, during the-last 200-years (Popovic et al., 1993). Over 100 serotypes of Vibrio cholerae exist, but generally the-toxigenic-strains of the-sero-group 01 cause cholaera, and possess documented-epidemic-potential. The-main-symptom of cholaera is a-profuse-diarrhoea, resulting-in dehydration, which, if untreated, leads-to death, within-hours. The-most-rapid-growth of V. cholerae O1 occurs in-moist and alkaline-foods. On most-food, V. cholerae 01 can survive from 2 to 14 days, better at 5-10°C than at 30-31°C. V. cholerae 01 also-seems to-survive-better on cooked-rather than on raw-food (Kolvin & Roberts, 1982).

According-to a-recent-report on Kenya, by WHO (2017): "The country experiences cholera outbreaks every year; however, large cyclical epidemics occur approximately every five to seven years and last for two to three years". For-example, from 1st January through 29th November, 2017, 20 of 47 counties (43%) in-Kenya have reported-cases. As of 29th November, seven-counties (Embu, Garissa, Kirinyaga, Mombasa, Nairobi, Turkana, and Wajir) continue to-have active-cholera-outbreaks. During the-same-period, a-total of 3967 laboratory-confirmed and probable-cases, including 76 deaths (case-fatality-rate = 1.9%) were reported by the-Ministry of Health, Kenya to WHO. Of-the-cases reported, 596 were laboratory-confirmed.

Up to 70% of diarrhea-cases, in-developing-countries, is said to-be-caused, by pathogens, transmitted, through-food (Kumiko et al., 2009). In-Kenya, in-particular, approximately 88% of diarrhea-associated-deaths is attributable-to unsafe-water, inadequate-sanitation, and unsatisfactory-hygiene, during food-preparation and consumption (Abuga et al., 2017). However, according to Gachuki (2012) the-incidences of food-borne-diseases are not easy to-estimate, in-Kenya, as most of them are unreported or under-reported. In-the-same-line, Gould et al. (2013) points-out, that " food-borne-diseases are possibly 300-350 times more-frequent, than what is reported".

Although most-individuals fully-recover, food-borne-illnesses can result in-chronic-health-problems, in 2 - 3 % of cases. Illnesses, such-as chronic-arthritis, and hemolytic-uremic-syndrome (HUS) leading to kidney-failure, have long-term-consequences for the-affected-individual, and for the-economy, and the-society, as a-whole. For-example, Health-Canada estimates that the-annual-cost, related to these-illnesses, and related-deaths, is between 12 and 14 billion dollars (FSWSG, 2008).

1.1.4. Food-born disease-causing-agents.

Food-born-pathogens cross-contamination, from-surfaces-to-food, can contribute-to food-borne-diseases (Miranda & Schaffner, 2016). These-diseases are caused by a-variety of etiological-agents, including: (i) Pathogenic-bacteria (e.g., Salmonella, Escherichia coli, or Shigella); (ii) Parasites (e.g., Cyclospora); (iii) Viruses (e.g., Norovirus); (iv) Fungi, protozoa, trematodes, and cestodes group; (v) natural-toxins (e.g., toxin-producing-organisms (i.e., Staphylococcus aureus or Bacillus cereus), and poisonous-plants); (vi) Chemicals (including heavy-metals), and (vii) Nematodes, among-others. Comprehensive-directory, of the-examples, of each-of the-listed-agents, can be found-in WHO (2008).
Moreover, transfer of pathogens, around the kitchen-environment, has been shown in many previous domestic-based-studies (see, for example, Kennedy et al., 2005; Gorman et al., 2002; Hilton & Austin, 2000).

1.1.5. Survival-rates and multiplication of food-borne-pathogens.
According to Kramer et al. (2006), most gram-positive bacteria, such as: Enterococcus spp., (including VRE), Staphylococcus aureus (including MRSA), or Streptococcus pyogenes, survive for months on dry-surfaces. Many gram-negative-species, such as Acinetobacter spp., Escherichia coli, Klebsiella spp., Pseudomonas aeruginosa, Serratia marcescens, or Shigella spp., can also survive for months. A few others, such as Bordetella pertussis, Haemophilus influenzae, Proteus vulgaris, or Vibrio cholerae, however, persist only for days. Mycobacteria, including Mycobacterium tuberculosis, and spore-forming-bacteria, including Clostridium difficile, can also survive for months on surfaces. Candida albicans as the most important fungal-pathogen can survive up-to 4 months on surfaces. Persistence of other yeasts, such as Torulopsis glabrata, was described to be similar (5 months) or shorter (Candida parapsilosis 14 days). In general, gram-negative bacteria have been described to persist longer, than gram-positive bacteria. Humid-conditions enhanced persistence, for most types of bacteria, such as Chlamydia trachomatis, Listeria monocytogenes, Salmonella typhimurium, Pseudomonas aeruginosa, Escherichia coli, or other relevant pathogen. Low-temperatures, e.g., 4°C - 6°C, also improved persistence of most types of bacteria, such as Listeria monocytogenes, Salmonella typhimurium, MRSA, corynebacteria, Escherichia coli, Helicobacter pylori, and Neisseria gonorrhoeae, among others.

Most viruses, such as corona, coxackie, influenza, SARS, or rhino-virus, can persist on surfaces for a few-days. Other viruses, such as astro-virus, HAV, polio or rota virus, persist for approximately 2 months. Blood-borne viruses, such as HBV or HIV, can persist for more than one-week. Herpes-viruses, such as CMV or HSV type 1 and 2, have been shown to persist from only a few-hours up to 7 days. The most-common pathogens may well survive, or persist on surfaces, for months, and can, thereby, be a continuous-source of transmission, if no regular-surface-disinfection is performed (Kramer et al., 2006). A low-temperature, such as 4°C - 6°C, was associated with longer-persistence for most bacteria, fungi, and viruses. High-humidity (e.g., >70%) was also associated with longer-persistence for most bacteria, fungi, and viruses (see Hayden et al., 2005; Neyle et al., 2005; Wilks et al., 2006; Neely & Maley, 2000; Maule, 2000).

On the other hand, food-safety is a scientific-discipline, describing handling, preparation, and storage of food, in ways, that prevent food-borne-illness (Abuga et al., 2017). According to the discipline, bacteria are the most-common cause of food-borne-outbreaks, since bacteria are microorganisms with high-reproductive-capacity. According to WHO (2015), bacteria multiply by a method, called ‘binary-fission’, where one bacterium becomes 2, and 2 bacteria become 4, etc. For example, Vibrio parahaemolyticus carries-out fission very quickly, and in conditions, which are good for the bacteria-growth, it can undergo fission once every-eight-minutes. If each bacteria splits-in-two, every-eight-minutes, after 3 hours there will be 4,200,000 bacteria and 68,919,470,000 bacteria after 5 hours!

From the above information, it can be put forward, that pathogens do not only survive, for a long-time, on-the-surfaces, but they are also able to multiply, rapidly, while conducive-environment, such as temperature, moisture, pH, and oxygen, can speed-up the growth of the pathogens.

1.1.6. Poor-hygiene-practices, during food-preparation and consumption.
World-Health-Organization (2008) estimates 40% of food-borne-disease-cases originate in-the-home, either directly or indirectly, through-avenues, such as cutting-board and knives (Gordon, 2018; Bloomfield & Nath, 2013). Analogous, most-countries report, that between 10% and 50% of food-borne-diseases, are associated with private-home-environment (see Bloomfield & Nath, 2013; Redmond & Griffith, 2003; Medeiros et al., 2001), via a range of contamination-routes (ADPHID, 2017), such as: cutting-boards; utensils (e.g., knives); counter-tops; surfaces (e.g., refrigerator-handles); food; and food-handler-hands.

According to van Asselt et al. (2008), up to 87% of the sites, where food-borne-diseases-outbreaks occur, are associated with foodstuffs, prepared or consumed in-households, where about 40 - 60% of the cases of food-borne-diseases are caused by inadequate-food and utensils handling-practices (de Jong et al., 2008), such as cross-contamination from cutting/chopping-boards (Ravishankar et al., 2010; Luber, 2009; van Asselt et al., 2009; Parry et al., 2005; Kusumangrumin et al., 2004). A finding from a resent-study, reported by Abuga et al. (2017), states that consumer-food-hygiene and safety-kitchen-practices were as low as 42.9%. Additionally, failure to associate the home as a potential-location to acquire food-borne-diseases may be a serious-barrier, for implementation of safe-food-handling-practices (Abuga et al., 2017).

Surface cross-contamination (for example via cutting/chopping boards) is the 6th most common contributing factor (out of 32) for food-borne-diseases (CDC, 2013; Gould et al., 2013; 2010). The next subsection introduces this food-contamination route.

Cooking-utensils, including cutting-boards and knives, washed in-contaminated-water, or food, contaminated, during or after preparation, e.g., moist-foods, contaminated, during or after cooking or preparation,
and allowed to remain, at room-temperature, for several-hours, provide an excellent environment for the growth of pathogens, e.g., *Vibrio cholerae* (World-Health-Organization, 2008). It is well-established that a high percentage of food-borne-illness is caused by failure of consumers to prepare food in a hygienic manner. Indeed, a common practice in households, is to use the same kitchen-equipment and surfaces, for both; raw meat and fresh produce (Gkana et al., 2016).

Microorganisms, attached to processing-equipment and surfaces, may escape cleaning and sanitizing procedures, and proceed to contaminate processed-product. Pathogens, originating with raw products, can attach to food-preparation-surfaces, which, if not adequately cleaned, before reuse, can serve to re-contaminate cooked foods (Frank, 2001). Figure 2 shows an example of indirect cross-contamination, where the same board and knife were used for raw meat and for raw vegetables (served as salad).

![Figure 2: Example of cross-contamination (FAO, 2017).](image)

Cleaning with cold-water and dish-soap, followed by vigorous-scrubbing and rinsing, practices commonly followed in household-kitchens, to clean cutting-boards, may reduce, but not eliminate the risk of exposure to the pathogens (Soares et al., 2012). Hypochlorite-disinfection, of cutting-board-surfaces, is considered as the safest and most efficient method (Soares et al., 2012), however many, if not all, households, are basically not aware of the dangers of inadequate cleaning and food cross-contamination. When utensils were not cleaned properly, after they were used, the transfer-rate was 1.25% from poultry to plastic-board-surface and 45.62% from plastic and knives to lettuce.

From the common methods, used in cleaning of surfaces, at homes, studies have shown that water and soap, alone, are not enough, to ensure de-contamination (Barker et al., 2003; Cogan et al., 2002; 1999; Scott & Bloomfield, 1990; 1993). To eliminate the cross-contamination route, it is important to use separate surfaces, or properly wash the surfaces, during the preparation of raw and cooked foods, or ready-to-eat foods (Sampers et al., 2010; Cogan et al., 1999); therefore, in the context of this study, separate chopping boards, for raw and for cooked-food, are preferable.

1.2. Research-purpose and selected-relevant issues.

1.2.1. Research-purpose.

Poor hygiene, during preparation and/or consumption of food, in conjunction with the ability of food-borne pathogens to survive (for a long time), and also to multiply, rapidly, can lead to food cross-contamination. Food cross-contamination, in turn, can lead to food born-diseases, resulting in some cases, in: (i) severe sickness, or even death (either immediately, or shortly, after food consumption), or (ii) in increased risk of chronic diseases (e.g., Guillain-Barre syndrome, or rheumatoid arthritis (CAST)).

Food safety issues are receiving growing attention, worldwide, due to ever-increasing incidence of food-borne diseases and their negative impacts on the public health, economy, and on the society, at large. Moreover, Luber (2009) points out that: “There is a focus in many countries to reduce the level of human illness from food-borne pathogens”. In the same spirit, this study is focused on a conceptual design of a kitchen utensils set of color-coded chopping boards and knifes, to reduce food cross-contamination at private homes, as well as at food establishments. Universal design approach was applied, to design a food chopping boards set, with particular emphasis on the people with color blindness condition; the next sub sections provide the background details.
1.2.2. Selected-relevant-issues.

1.2.2.1. Chopping-boards and materials, used in their-fabrication.

A-cutting, or chopping-board, is a-durable flat-board, on which to-place a-product/material, for cutting. The-kitchen-cutting-board is commonly used in-preparing-food, and it-is also-called food-chopping or food-cutting-board, is an-indispensable kitchen-utensil. Such-boards are often made-of different-materials (see selected-examples in Figure 3), and come in-various-shapes and sizes.

With-regard-to materials, stainless-steel has often-been-considered the-optimal-material-choice for commercial-food-preparation-surfaces, because of its-resistance-to corrosion and chemical-degradation, mechanical-strength, and ease of cleaning (Wilks et al., 2006), although stainless-steel may have higher-bacterial-transfer-rates than other-surfaces (Wilks et al., 2005; Robine et al., 2002). A-study by Soares et al. evaluated four-types of materials, used-as cutting-surfaces, for food-handling: pine-wood; triclosan-treated- plastic; tempered-glass, and stainless-steel. Among the-surfaces analyzed, wood was considered to-be the-most-difficult to-clean, while stainless-steel was the-easiest (Soares et al., 2012).

![Figure 3: Selected-examples of the-Materials used for chopping-boards.](image)

**Keys:** 1 - Stainless-steel; 2 - Acrylic; 3 - Granite; 4 - Marble; 5 - Teak; 6 – Bamboo; 7 - Walnut; 8 – Acacia.

In-particular:

(i) *Wood* is, somewhat, self-healing; shallow-cuts in-the-wood will close-up, on-their-own. Wood also has natural-anti-septic-properties. On-the-other-hand, wood is intrinsically-porous, which allows food-juices and bacteria, to-penetrate the-body of the-wood; the-moisture is drawn inside, in-by-the-capillary-action, until there is *no* more free-fluid on the-surface, at which-point immigration ceases. Bacteria, in-the-wood-pores, are *not* killed instantly, but neither do they return to the-surface (Cliver, 2006; Abrishami et al., 1994). Hard-woods, with tightly-grained-wood and small-pores, are best for wooden-cutting-boards, which help to-reduce absorption of liquid and dirt, into-the-surface. There are different-types/species of wood, which are used for cutting-boards (Aviat et al., 2016; Xi et al., 2013; Milling et al., 2013), for-example:

*Acacia* cutting-board is often-labeled as the-top-choice for this-kitchen-item; usual-maintenance (oiling), however, is required, to-prevent them from splitting. Acacia is a-highly-sustainable-wood; it has the-appearance of bamboo, but without the-need for international-export.

*Walnut* cutting-board is the-most-expensive of the-wood-cutting-boards, walnut is a-strong and durable-material, however it needs maintenance with oil, regularly, otherwise, they can develop very-deep-cracks, making it unhygienic.

*Teak* cutting-board; Teak, a-tropical-wood, contains tecto-quinones-components of natural-oily-resins, which repel moisture, fungi, warping, rot, and microbes. Teak is also-known for being a-very-durable and water-resistant-form of wood, and for-this reason, it-is a-popular-choice for cutting-boards. Although little-pricy, due-to-its-density, there is minimal-scarring and scratching done, to-it, when used for food-chopping. Besides, teak-cutting-board does *not* require oiling; Teak-wood’s tight-grains and natural-coloration make it a-highly-attractive cutting-board-material, both; for aesthetic and durability-purposes. It is important to-note, however, that there are
cutting-boards, made from African-Teak or Rhodesian-Teak, which despite the-name, are not made from the-same-species of wood.

Cherry cutting-board has softer-texture, which, on-one-hand, will be helpful in-protecting knives from damage, but it may also-cause more-damage to the-wood, itself. These-boards should never be submerged in-water, or placed in a-dishwasher, just like the-other-wood-varieties. Another-issue is that the-board should be-at least 2 inches, in-thickness, as it can crack easily; regular oiling, proper-washing, and disinfection are needed.

(ii) Bamboo, although commonly-listed under ‘wood’, strictly-speaking is not a-wood; the-distinguishing-features is that bamboo grows very-fast, while wood not, also these-materials have fundamentally-different internal-structure. Bamboo-cutting-boards are considered to-be-naturally-anti-microbial; they can be produced, from multiple-pieces, by lamination. Bamboo has long been a-popular-alternative for wood, in-many-areas, not just with cutting-boards. The-biggest-concern, however, is the-sustainability of the-material. Compared to most-woods, bamboo has a-very-fast re-growth-rate, making it ideal for a-range of products. As most-bamboo is sourced in-China, there is an-issue of questionable-labor-practices, and the-energy-spent, to-transport the-product, cancelling-out the-sustainable-factor. In-terms of cutting-board-quality, bamboo will require some-maintenance, as it can be quite-hard-to-the-touch, and is prone-to splitting and cracking.

(iii) Plastic-boards are usually-called PE (polyethylene) cutting-boards, or HDPE (high-density-polyethylene-plastic), can be made from injection-molded-plastic, or from an-extrusion-line. Polyethylene-cutting-boards have been-around, for many-years; and proven to-be the-cheapest and effective-types. Most-HDPE-boards are specifically-designed not to-dull the-edge of a-knife. High-density-polyethylene, which is the-most-used in commercial-applications, has been shown to-delaminate, in-response-to knife-scarring (Gkana et al., 2016; Cliver, 2006).

(iv) Marble cutting-boards are known for being one of the-most-hygienic-forms, due-to their-non-porous nature, and ease of cleaning; however, they can do some-damage to the-knives, because of their-tough-surface.

(v) Granite is another visually-pleasing-material-choice for cutting-boards, however such a-board will dull the-knives, and it can be noisy, during food-chopping.

(vi) Maple cutting-board is considered to-be the-most-expensive, on-the-other-hand it will not damage the-knives, and will help to-prolong its-life significantly. Cleaning a-maple-cutting-board is relatively-simple, and is it non-porous-material, hence fewer-bacteria and less-water can seep through.

(vii) Stainless-steel cutting-boards are not as-common-as the-previously-mentioned-types. Steel-boards are durable and easy to-clean; they do not warp or swell, like some-wood varieties can, and there is no need to-oil them, or perform any-other-maintenance. However, these-boards can damage the-knives significantly and also cause them to-slip, on the-surface, during use. Besides, the-sound of a-knife, against stainless-steel, particularly when chopping quickly, is not pleasant.

(viii) Acrylic cutting-board is cheap and effective, it-is probably be the-second-choice, after polyethene; such a-board can be submerged in-water, or even washed in-the-dishwasher, hence, it is very-easy to-maintain, however, it should-be sanitized, and replaced every 12 months; making it an-expensive-option.

(ix) Rubber boars are as-expensive-as well-made-wooden-boards, and in-addition they do smell. They can withstand chemical-disinfectants, and they are very-heavy for their-size, so they tend not to-slip. Besides, they exhibit self-healing-properties.

(x) Like-rubber, silicone is soft on the-knife-blade, while being just as self-healing and anti-bacterial, as-wood. Silicone is also heat-resistant, and lacks the-rubber-smell of rubber-boards, but it is expensive.

(xi) Glass cutting-boards are easily-cleaned and they are more-hygienic, however, they can damage knives, harsh-noises are produced, while in-operation, and due-to their-slick and hard-surface, a-knife can easily-slip, while cutting, and cause a-potential-hazard in-the-kitchen. Also glass-board can be easily broken, especially during washing. In-general, glass-cutting-boards are likely-going-to-do more-harm than good.

Numerous-materials can be used, to-produce chopping-boards; each has its-advantages and limitations. For-example, wood, in-general, is said, to-dull knives, less-than plastic, and plastic is seen as-less-porous, than wood (Cliver, 2006); the-wooden-boards, however, should be-regularly oiled, by edible-mineral-oil, to-avoid warping and splitting. Besides, wooden-cutting-boards do not get cuts, as-deep-as plastic. This means the-bacteria cannot become trapped, and will dry-out, eventually. The USDA’s Food-News for Consumers recommended strongly that plastic, not wooden, cutting-boards be used in consumers’ kitchens. However, a-study by Ak et al. (1994), indicates, that wood had some-sort of antibacterial-effect, which was not found in-plastic.

1.2.2.2. Universal-design concept.

Universal-Design (UD) means the-design of products, environments, programs, and services, to-be-usable by all-people, to-the-greatest-extend-possible, without the-need for adaptation or specialized-design (Vanderheiden, 1997). Seventeen-percent of the-U.S.A.-population has some-form of disability (ADA, 2010; Erickson & Lee, 2003), numbers are similar, worldwide; besides, probability of people developing a-disability increases-with-age.
As the population of people with disabilities grows, so does the ethical and economic pressure, to provide that population with products, which offer services and value. Nevertheless, many product-designers and companies are unfamiliar with approaches to applying UD (a term, commonly used to describe goods and services, which are usable by both; by persons with a disability and by typical-users (McAdams & Kostovich, 2011)). Universal-design is an active-research area; nevertheless, formal methods for the design are limited in scope (Danford, 2003; Preiser & Ostroff (Eds.), 2001; Bowe, 2000). UD is used interchangeably with Inclusive design (the term, which mainly used in the United Kingdom (Goodman et al., 2006)), meaning that the design can be used, equally well, by people of any ability; in other words, it does not discriminate against users, based on their ability. In addition, each of the Trans-generational, Rehabilitation-design, and Adaptable-design, do share common elements with UD (Erlandson, 2008; Connell, 1997; Hewer, 1995; Peloquin, 1994).

This study applies UD-concepts and principles, with particular emphasis on people with color-blindness condition.

1.2.2.3. Color-blindness condition.

Color-blindness, also known as color-vision-deficiency, is the decreased ability to see color, or to differentiate colors (to a certain degree or completely) (NEI, 2015; Gordon, 1998). Color-blindness does not mean, however, that a person can only see black and white. Two major types of color-blindness are: (i) difficulty distinguishing between red and green; and (ii) difficulty distinguishing between blue and yellow. Based on clinical appearance, color-blindness may be described as total or partial; while total-color-blindness is much less common, than partial-color-blindness (Hoffman, 2008; Spring et al., 2007; Neitz, 2007).

According to Blom (2009); Shevell (2003); and Stiles & Wyszecki (2000), total-color-blindness (‘monochromacy’) is a very rare condition, in which, people only see different tones and brightness levels, with no color, at all. Although the term may refer to acquired disorders, such as cerebral-achromatopsia, also known as color-agnosia, it typically refers to congenital-color-vision disorders (i.e., more frequently rod-monochromacy, and less frequently cone-monochromacy) (EIZO, 2006).

The various types and characteristics of partial-color-blindness (Wong, 2011; Simunovic, 2010; McIntyre, 2002) are: (i) Anomalous-Trichromacy (a mild shift in the sensitivity of the cones); (ii) Protanomaly (shades of red appear weaker in depth and brightness); (iii) Deuteranomaly (shades of green appear weaker); (iv) Tritanomaly (a very rare condition, in which shades of blue appear weaker); (v) Dichromacy (severe deficiency or complete absence of one of the types of cones); (vi) Protanopia (shades of red are greatly reduced in depth and brightness, if they can be seen, at all); (vii) Deuteranopia (shades of green are greatly reduced in depth and brightness, if they can be seen, at all); (viii) Tritanopia (a very rare condition, in which shades of blue are greatly reduced in depth and brightness, if they can be seen, at all).

Color-blindness affects a large number of individuals, with protanopia (red deficient: L-cone absent) and deuteranopia (green deficient: M-cone absent) being the most common types. In individuals with Northern-European ancestry, as many as 8% of men, and 0.4% of women, experience congenital color deficiency (Chan et al., 2014). Likewise, according to the Howard Hughes Medical Institute, in the United States, about 7% of the male population, or about 10.5 million men, and 0.4% of the female population either cannot distinguish red from green, or see red and green, differently from how others do (HHMI, 2006). Color-blindness or color-vision-deficiency also affects about 2.7 million people in Britain. In Australia, around 8.0% of the male population is color-blind, compared to around 0.4% of the female population. The ability to see color also decreases in old age.

Being color-blind may make people ineligible for certain jobs, in several countries. This may include being a pilot, train driver, traffic police officer, and working in the armed forces (NEI, 2015; Wong, 2011). Regardless of the types, rights of the color-blind people have been protected, in some states; for example, according to the Decree, issued by president of a republic, ratifying Legislative-Decree No. 198, of June 13, which approved the Inter-American-Convention AG/RES. 1608, “A Brazilian court ruled that people with color blindness are protected by the Inter-American Convention on the Elimination of All Forms of Discrimination, against Person-with-Disabilities”, e.g., the carriers of color-blindness have a right of access-to wider knowledge, or the full enjoyment of their human condition. In the United States, however, under federal anti-discrimination laws, such as “the Americans with Disabilities Act”, color-vision deficiencies have not yet been found to constitute a disability, that triggers protection from workplace discrimination (Larson, 2016; Zhang, 2014).

This study assumes that color-blindness is a sort of a disability; universal-design approach, to be used, to consider the condition, by incorporating easy recognizable symbols, since colors of the chopping-boards and cutting-knives, cannot be distinguished, by the people with color-blindness.

2.0. Materials and Methods.

The aim of this research was to design a cost-effective, easy producible, user friendly, and reliable kitchen utensils set, that can be used to reduce food cross contamination. The design followed steps of the fundamental Engineering Product Design (see Starovoytova, 2019a; b; 2018); Figure 4 shows the chronological steps,
In particular:

Review of cross-contamination-mechanism was done by the examination of the available-published-literature on the subject-matter.

Evaluation of chopping-boards designs was conducted by the desk-study-approach and by non-participant-observation. Selected-relevant-patents, as well as similar-products, available locally and internationally, were analyzed. In particular, a non-participant-observation, across the various local-supermarkets, within the locality of Eldoret-town, Uasin-Gishu-county, and online market-platforms, such as Jumia and Kilimall, were conducted, to determine the availability of chopping-board-sets; Inclusion of knives in the-sets; availability of labels; and different-materials, used in their fabrication, among other issues.

Selection of PRD was done via comparative-analysis of the results, obtained from the previous step, by identification of the most-advanced-set (at the time of the study), and most suitable (for this unfunded study) design.

Examination of limitations of PRD was done by the critical-inspection of the PRD, as well as from the available-reviews, expressed by some users of the set, at the official cite of the product (see, for example: https://www.josephjoseph.com/en-rw/index).

Development of four-design-alternatives, were done by the individual-design-team-members; the end-result is four-hand-sketches. Besides, some preliminary-calculations were done, at the same-time, which might be required to substantiate ideas and to establish approximate sizes.

Selection of the best-design-alternative; This study used a standard Engineering-Design Weighted-Decision-Matrix (EDWDM), to select the best design-alternative. In addition, analogous to Starovoytova (2019 a; b) and Starovoytova & Namango (2016), to confirm the choice, additional-method, of selection of best-design-alternative, was used, namely ‘D & R-method’.

2D drawing, of the best design-alternative, was created via computer-aided-design (CAD) AutoCADsoftware, while Autodesk-Inventor-Version: 2016 (Build 200138000, 138) was used for 3D modeling.

Preliminary-materials-selection; Materials selection plays an essential role in the product design process (Doordan, 2003), where 4 elements (function, shape, materials, and manufacturing-processes) do interact. Ashby & Johnson (2003; 2002) identify four materials-selection methods: (i) ‘Analysis’; (ii) ‘Synthesis’; (iii) ‘Similarity’; and (iv) ‘Inspiration’ method. This study adopted the ‘analysis’ method, where a list of product requirements is translated into material objectives and constraints. The main objectives of the intended set, was used as a guide, in materials selection. Besides, the study adopted the interaction of function, materials, shape, and manufacturing-processes, from Ashby (1999), and the interaction of use, function, materials, and shape, from Roozenburg & Eekels (1995).
3. Results.

3.1. Examination of available-designs.

A number of relevant International-patents (developed by individuals, as well as design-companies) were reviewed; examples included: US 9,155,427 B1 (2015); US D655,939 S (2012); US 8,220,789 B2 (2012); US D638,265 S 5 (2011); US 8,070,148 B2 (2011); US 7,681,871 B2 (2010); US14814 A1 (2010); US 2007 23 A1 8 (2009); US 0146353 A1 (2009); US 0080487 A1 (2007); US 0001359 A1 (2007); US 19221 A1 (2004); US 0046301 A1 (2004); and US 0195763 A1 (2002).

Figure 5 shows selected-examples of different-food-chopping-boards, available in the-local-supermarkets, while Figure 6 demonstrates the-array of products, available on-line.

Figure 5: Most-common food-cutting-boards, available at-selected-local-supermarkets.

Keys: 1 - wooden; 2 - plastic; 3 - bamboo.

Figure 6: Selected-examples of boards, available for purchase, on-line.

Keys: Upper-row (Left – “Ultra-Thin Fruit Vegetable Chopping-Board Anti-Bacteria Mat Kitchen Tool’ (set of 4); Right – ‘Wheat-Straw Cutting-Board Gourmet-Chopping with Grinding-Garlic-Tool’ (set of 4). Lower-row (Left – ‘2 In 1 Creative Foldable Cutting Board with Storage Basket Box for Cooking Tool’; Middle – ‘Multifunctional-Drainage-Plastic Chopping-Board’; Right- ‘Expandable Chopping-Board’).

The-assessment revealed, that: (i) none of the-patents, examined, have featured a-complete-set of color-coded boards and knives; (ii) Local-supermarkets, mostly-offered individual-food-chopping-boards (no sets), besides, none had knife-provision; and (iii) Selected-products, available on-line, were pricy, especially for people, in-developing-countries, like Kenya.

3.2. Point of Reference for the-design (PRD), and its-limitations.

Following critical-assessment of available-designs, this-study has chosen Joseph Joseph Index™ Color Coded Chopping Boards set, as a-point of reference for the-current-design (due to its-uniqueness and appropriateness, to-prevent/limit food-cross-contamination. Joseph Joseph Index™ Color Coded Chopping Boards set, designed by
Damian Evans, and since its-launch, in 2008, has been a-worldwide-best-seller (at USD 50); Figure 7 shows the-PRD.

![Figure 7: Joseph Joseph Index™ Color Coded Chopping Boards (set of 4)](image)

**Figure 7** shows contemporary ABS-storage-case with a-non-slip-base; Boards are stored in-staggered-order, for visual-ease; Illustrated-tabs/labels provide at-a-glance-reminder, which board is which. Besides, the-operational-manual indicates that, boards are dishwasher-safe.

### 3.3. Identified-limitations of the-PRD.

Several-limitations of the-Joseph-Joseph Index™ Color-Coded Chopping-Boards (set of four) were identified (by the-physical-observations and from the-product-users-review-blog), and in-particular: (1) the-boards, inside the-casing, are touching each-other, hence, there could be-cross-contamination from one-board to the-neighboring one(s); (2) no drainage-perforations, at the-bottom of the-set, which could lead-to moisture-accumulation, within the-set; (3) no knife, or knives, included in the-set; (4) protruding-labels tend to-wear-out and become less-visible (as they are used to-get the-boards out of the-casing), hence, losing its-primary-function; (5) according to Ergonomic-design-principles, pinch-grip, used to-get the-boards from the-casing, is much-weaker than the-power-grip (see Starovoytova, 2018), making the-set un-agronomical; (6) There are no board-handles, hence it-is rather-difficult to-remove individual-boards, from the-casing; and (7) no provision for a-separate-board, specifically for raw-poultry-meats (according to the-Oxford-Dictionary (2018), poultry is the-inclusive-term for chicken, turkey, and duck-meat, as-well-as pheasants, and other-less-available-fowl).

### 3.4. Generation of the-design-alternatives.

This-study is based on the-major premise, that according-to Gkana et al. (2016): “Separate-cutting-boards and knives, should-be-used, for processing raw-meat and preparing ready-to-eat-foods, in-order-to-enhance food-safety”. In-particular, the-current-design is to-address the-identified-above-limitations, by incorporating: (i) separation-plates, between the-boards, inside the-casing; (ii) perforations, within the-removable-bottom of the-casing; (iii) five-colour-coded-knifes, matching colours of each-of the-five-boards; (iv) a-permanent-labels (engraved) on the-boards, knives, and the-set-casing; and (v) ergonomically-designed-handle for the-board. Where, Separation-plates (vertical-plates, running-through opposite-sides of the-casing, whereby on one-side they cover the-whole-surface, while on the-other-side they cover halfway, with the-side-left open); Perforations (a-series of small-holes, which cover the-whole-bottom-surface of the-casing); Basement (a-separate-block with a-compartment for holding draining-water, which can be attached, or detached, from the-main-casing-interface); Labels (well-embossed-symbols on a-slanted-surface on one-side of the-casing, and on every board and knife); Board withdrawal ( the-boards are laid in-such a-way, that the-handles protrude the-outside-surface, of one-side of the-casing, and their-withdrawal is in-a-horizontal-manner); and Knife-inclusion (the-knives are placed in-compartment-block, within the-casing, which has small-open-spaces, upon which the-cutting-blades of the-knives can be inserted).

Several-other-issues were also-taken into-account, during the-design-stage, of this-study. First, it was considered, that any-device usually comprises of various-parts. The-utilitarian or functional-part is the-one that truly-performs basic-task, which prompts the-execution of the-segment. The-non-functional-part does not have real-work in-segment-presentation, but rather it needs to-do-with support, spreads, examination, and aesthetical-worth,
and therefore, the number of non-functional parts should be reduced, to cut the cost (Juvinall & Marshak, 2012; Budynas-Nisbet, 2008).

Besides, the designed set should be: (i) manufactureable/easy-producible (using locally-available equipment and expertise; and being able to be easily and effectively-colored, in five distinct colors); (ii) cost-effective; (iii) soft; and light-weight; (iv) reliable; structurally-sound; and durable. And, as explained above, be functional, hence, components which are not important/functional should be eliminated.

Moreover, the device should be: Efficient (in reducing food-cross-contamination); Functional (easily-maintained, user-friendly); Pleasant, in appearance (suitable size and shape, attractive design, good finishing); Durable (not easily-broken, stable, and robust-design, strong sound-structure); and Safe (harmless to the user, no side-effects, and environmentally-friendly). To achieve these criteria, structurally, all the components should: (a) be symmetrical (and have polar-geometry-mark), if possible, as this also helps in manufacturing; (b) have consistency, in the-dimensions, used for feeding, orientation, and location; and (c) have location-points (see Starovoytova, 2019a for more details).

Lastly, the following account will try to justify the decision, made by the design-team, that one additional board (for poultry raw meat), is necessary. While numerous potential vehicles of food-borne-transmission exist, poultry meat has been identified as one of the most important food vehicles for the food-borne-diseases (Silva et al., 2011; FAO & WHO, 2009). Salmonellosis and Campylobacteriosis are among the most frequently reported food-borne-diseases, worldwide (Bollaerts et al., 2008), and Enteritidis is the main serotype responsible for human infections (Moore et al., 2007; Pang et al., 2007; Oliveira et al., 2006). According to Shu-Kee et al. (2015), Salmonellosis accounts for 93.8 million food-borne-illnesses, and 155,000 deaths, per year. Although only 20–40% of the food-borne-diseases cases are associated with chicken meat, consumption of chicken is still the predominating factor for Campylobacteriosis (Humphrey et al., 2007). Illnesses via chicken meat can occur either by undercooking or by cross-contamination.

From the results of a study by Adetunji & Isola (2011), it can be concluded that the cross-contamination, between raw and processed foods, by surface-contact is hazardous, because Salmonella can adhere to the surface, and form a bio-film, resulting in a source of contamination. In addition, a relatively recent study revealed that two thirds of consumers failed to adequately wash hands, after handling raw chicken, nearly 30 percent failed to wash, or change the cutting-board, after cutting raw chicken, and one third failed to wash, or change a knife, used to cut raw chicken meat, before cutting raw vegetables (WHO, 2006; 2002).

Salmonella pathogen is a rod-shaped, Gram-negative facultative anaerobe, which belongs to the family Enterobacteriaceae (Barlow & Hall, 2002). To date, over 2500 Salmonella serotypes have been identified, and more than half of them belong to Salmonella enterica subsp. enterica, which accounts for the majority of Salmonella infections in humans. In human infections, the four different clinical manifestations are: (i) enteric-fever, (ii) gastroenteritis, (iii) bacteraemia, and other extraintestinal complications, and (iv) chronic carrier state (Sheorey & Darby, 2008). Salmonella infection contributes to the economic burden of both industrialized and developing countries, through the costs, associated with surveillance, prevention, and treatment of the disease (Majowicz et al., 2010; Crump et al. 2004).

The four design alternatives generated by the design-team, are shown in Figure 8.

3.5. Selection of the best design alternative.
Alternative design # 4 was selected, via standard-EDWM, with the highest score of 0.82; while Alternative # 1 scored 0.53; Alternative # 2 – 0.47, and Alternative # 3 – 0.65.

3.6. Description of the best design alternative, including its 2D-drawing and 3D-modeling.
Regarding the dimensions of the set, the cutting-board size acts as the primary determinant of the sizes of other components of the designed set; board dimensions (L x B x T) of 30cm x 20cm x 10mm were chosen (as one of the most common board sizes, currently used, worldwide).
Figure 9 shows two-dimensional-drawing of the-main elements of the-set, with sizes; Figure 10 demonstrates the-set-assembly of the-best-alternative-design, while Figure 11 shows colour-corded-boards and the-position of labels; Figure 12 and Figure 13 show labels/symbols and dimensions of the-set-components, respectively.

Figure 9: 2D drawings of the-main-elements of the-design-set.

Figure 10: Set-assembly of the-best-alternative-design.

**Keys:** 1 - Basement; 2 - Stand; 3 – Boards (five); 4 – Knifes (five); 5 – Separation-plates; 6 – Labels/symbols; 7 – Handle of the-board; 8 – Perforations (see Figure 13 for details)
Labels (positioned on each-board and each-knife, as-well-as on the-set itself, as an-inclined-panel) were introduced, to-cater for the-people with color-blindness (according to-the-fundamental-principles of the-Universal-design), and also to-avoid confusion (as a-reminder which board is which, to all-users).

**Figure 11:** Color-coded-boards and the-position of labels.

1 – Blue (raw sea-food); 2 – Green (raw fruits and vegetables); 3 – Yellow (raw-poultry); 4 – Red (raw meat); 5 – Brawn (cooked food).

**Figure 12:** Labels/symbols.

**Keys (left to right):** Blue (for Raw-Fish); Brown (for Cooked-food); Yellow (for Raw-poultry); Red (for Raw-meat); and Green (for Raw-fruits and vegetables).

3.7. Materials-selection.

The-engineering-materials of mechanical and structural-engineering fall-into the-broad classes/families (Asby, 2010; 2005), such-as: (i) Metals (the-metals and alloys); (ii) Polymers (the-thermoplastics and thermo-sets); (iii) Elastomers (engineering-rubbers, natural and synthetic); (iv) Ceramics, technical-ceramics (Fine-ceramics capable of load-bearing-application), and Ceramics, non-technical (porous-ceramics of construction); (v) Glasses; and (vi) Hybrids (hybrids: composites; hybrids: foams; and hybrids: natural-materials).

According-to Ashby (2004), the-very-first-consideration, in-materials-selection, is on the-functionality of the-material; the-main-goal here is being-able to-produce products that function effectively, safely, and at-acceptable-cost. The-functionality relates three-aspects, namely: (i) the-function of design-component (what it does), (ii) its-objective (intended-achievement), and (iii) constraints (limits to performance). In-this-study, the-function of cutting-board is to-aid in-food-chopping-operations, with main-objective being elimination/reduction of food-cross-contamination. The-most-essential (and hence important)-constraint, in the-initial-consideration of materials-selection, in-this-study, is the-ability of a-material to-be-dyed/colored in five-solid-colors (so-called ‘color-coding’). Besides, a-knife-edge is a-delicate-structure, and can easily-be-blunted by a-surface, which is too-abrasive. A-good-cutting-board-material, hence, should be-relatively-soft, easy to-clean, and non-abrasive, but not fragile, to the-point of being-destroyed. A-good-cutting-board-material should be also less-porous, to-prevent moisture-absorption, which facilitate bacteria thrive and cracks. Other-constraints include manufacturability, cost, porosity, health and safety-issues, etc.
This study adopted so-called ‘screening’-approach to materials-selection, where (Dobrzanski, 2001) elimination of materials starts by comparing their-attributes and limits, set by constraints, hence, if limits are not met, the-material is eliminated. Only 2 material-suitable-groups of materials were pre-selected, namely: (i) Polymers/plastic; and (ii) Hybrids: Composites. Afterwards, the-composites-group was eliminated, due-to-lack of composites-manufacturing-equipment and expertise, in-Kenya, leaving the-group of polymer/plastics uncontested.

It is important to note, however, that there are over 60 materials in the ‘polymer/plastic’ group. Figure 14 shows a-comparative-property-chart, for selected-plastic-materials. The-main-properties for comparison, used here, are: cost (should be as-minimum-as possible), moisture-absorption (low), and tensile-strength (high).

From the-chart, it can be observed that polyethylene-materials are superior, based on-cost and moisture-absorption-properties; however, it is not a-clear-cut, as they are of lower-tensile-strength. The-polyethylene-materials were selected, for further-screening; their-background-information follows.

Polyethylene or polythene (abbreviated PE; IUPAC name polyethene or poly(methylene)) is the-most-common-plastic. As of 2017, over 100 million tons of polyethylene-resins are produced, annually, accounting for 34% of the-total-plastics-market. Polyethylene is classified by its-density and branching. Its-mechanical-properties depend-significantly-on variables, such-as: the-extent and type of branching, the-crystal-structure, and the-molecular-weight. There are several-types of polyethylene (Kurtz, 2015): (i) Ultra-high-molecular-weight polyethylene (UHMWPE); (ii) Ultra-low-molecular-weight polyethylene (ULMWPE or PE-WAX); (iii) High-molecular-weight polyethylene (HMWPE); (iv) High-density polyethylene (HDPE); (v) High-density cross-linked polyethylene (HDXLPE); (vi) Cross-linked polyethylene (PEX or XLPE); (vii) Medium-density polyethylene (MDPE); (viii) Linear low-density polyethylene (LLDPE); (ix) Low-density polyethylene (LDPE); (x) Very-low-density polyethylene (VLDPE); and (xi) Chlorinated polyethylene (CPE).
Figure 14: Plastics-polymers
(Precision Punch & Plastics manufacturing-company, U.S.A.)

Keys:

PE is usually a-mixture of similar-polymers of ethylene, with various-values of \( n \). Polyethylene is a-thermoplastic; however, it can become a-thermo-set-plastic, when modified (such as cross-linked-polyethylene). Polyethylene is of low-strength, hardness and rigidity, but has a-high-ductility and impact-strength, as-well-as low-friction. It shows strong-creep, under persistent-force, which can be reduced by addition of short-fibers. It feels waxy, when touched. The commercial applicability of polyethylene is limited by its-comparably low-melting-point. Higher-crystalinity increases density and mechanical and chemical-stability. Polyethylene absorbs almost \( \text{no} \) water. The-gas and water-vapor-permeability (\( \text{only} \) polar-gases) is lower than for most-plastics. In-particular, selected-data/properties for PE, are:  Chemical-formula - \((\text{C}_2\text{H}_4)_n\); Density - \(0.88–0.96\) g/cm; Melting-point - \(115–135 \)°C \((239–275 \)°F; \(388–408 \)K); \(\log P\) - \(1.02620\) (data are given for materials in their-standard-state (at \(25 \)°C \([77 \)°F], \(100 \)kPa) (Geyer, 2017; Kurtz, 2015; Batra, 2014).

Considering that there are 11 types of polyethylene; the-study recommends to further-investigating which polyethylene-type is the-most-appropriate for this-particular design-set.

4. Discussion.
As-mentioned-earlier, a-substantial-proportion of food-borne-diseases has been-linked-to poor-food-preparation and hygienic-practices, in-the-home (Redmond & Griffith, 2003). Cutting-boards are recognized as-possible-sources of cross-contamination, with pathogens, as-well-as spoilage-bacteria (Cliver, 2006; Carpentier, 1997). Bacteria may grow, or survive, for a-long-time on cutting-boards, which may subsequently be a-source for contamination of ready-to-eat-foods (Todd et al., 2009). Surveys show inadequate-handling of cutting-boards (lack-of or insufficient-cleaning) for 30–90% of consumers (Redmond & Griffith, 2003). Common-cleaning-procedures, used by consumers, at home, may \(\text{not} \) be sufficient to-completely remove pathogens from contaminated-cutting-boards (Cogan et al., 2002). According-to the-Food-Protection-Trends (2004), bacteria, on a-cutting-board, can double, after 10 minutes of use, whether cutting raw-meat or vegetables. The-discrepancy, between knowledge and practices, shows that consumer-education is \(\text{not} \) enough, to-prevent unsafe-practices, and has provided a-market for products with claimed-antimicrobial-activity (Aider, 2010; Marambio-Jones & Hoek, 2010; Monteiro et al., 2009; Moretro et al., 2011; 2010; 2006). The-global-antimicrobial-compounds (AMCs)-market is estimated-to-be worth USD 3 billion, and projected to-grow to USD 4.5 billion, and 590 kilotons, by 2020 (Grand View Research, 2013). Commercially-available-AMCs can-be-divided (Rosenberg et al., 2019) into: (i) powder-coatings, which can be electro-statically-layered to various-surfaces, and (ii) surface-modification-coatings, that interact-with application-surface and confer-protection against-pathogens. They can be applied-to surfaces \( \text{via} \) spraying, draw-down-method, thin-film-coating, and spin-coating (Grand View Research, 2013).

In-recent-years, antimicrobial-polymers and coatings have-gained-interest, from both; academia-research and as industrial-products, due-to their-potential to-provide higher-quality-life and safety. Antimicrobial and antibacterial-agents are materials, capable of killing pathogenic-microorganisms. Surface-modification that
effectively kills microbes, on-contact, without releasing a biocide, represents a modern and efficient approach, toward continuous and permanent-sterile materials. The undesirable-growth of microorganisms, on solid-surfaces, that is, bio-fouling, or bio-contamination of surfaces, represents an important threat in diverse surface settings, for example, medical-implants (Hetrick & Schoenfisch, 2006); water-purification (Nguyen et al., 2012); or food storage and preparation (Hannon et al., 2017). Substances and food-contact materials are antimicrobial materials, if they realize “a reduction of Colony Forming Units (CFU) > 2-log” (Moerman, 2013).

The antimicrobial compound may be incorporated throughout the materials, or added, as a coating, on the surface of the material. The antimicrobial agents can be of organic and inorganic origin.

Organic antimicrobial agents, including: (i) Silver - containing antimicrobial materials (e.g., Silver-ions; Silver-bearing stainless-steel; and Silver-nano-particles); (ii) Copper - containing antimicrobial materials (e.g., Copper-ions, Metallic-copper, Copper-alloys, Copper-bearing stainless-steel, Copper oxide nano-particles); (iii) Zinc - containing antimicrobial materials (e.g., Zinc-ions, Zinc-oxide nano-particles); and (iv) Titanium - containing antimicrobial materials (e.g., Titanium, Titanium-dioxide, Titanium-dioxide nano-particles).

Organic antimicrobial agents include: Triclosan N-halamine containing surfaces; Quaternary ammonium compounds immobilized on surfaces; Organosilane quaternary ammonium compounds; and N-alkylated-polyethyleneimines.

For more details, on each, of the listed above agents, see Moerman (2013).

Hydrogels is the most-important family of hydrophilic-adhesion-resistant coatings. A hydrogel is a three-dimensional (3D) network of hydrophilic-polymers that can swell in water, and hold a large amount of water, while maintaining the structure, due to chemical or physical cross-linking of individual polymer chains. By definition, water must constitute at least 10% of the total weight (or volume) for a material to be a hydrogel (Bahrami et al., nd; Wichterle & Lim, 1960). There are four major categories of polymers and coatings, such as (Baghdachi et al., 2015): (i) polymeric coatings, with QA-groups; (ii) polymers with quaternary-phosphonium groups; (iii) norfloxacin containing-polymers; and (iv) polymeric-N-Halamines-group.

Besides, Triclosan is considered for a polymer additive, with multiple properties, to be an antimicrobial, with additional benefits, as a non-polar toughening agent, and a hydrophobic wetting agent (Petersen, 2016). Triclosan, 2, 4, 4’-trichloro-2’-hydroxydiphenyl-ether, has broad-spectrum antimicrobial effect, acting through multiple mechanisms at high-concentrations, while inhibiting fatty acid-synthesis at sub-lethal concentrations (Jones et al., 2000; Levy et al., 1999). It has broad-spectrum activity at low-concentrations, to inhibit both gram-positive and gram-negative bacteria, and also different viruses and fungi (SCCS, 2010; CSC, 2001). Triclosan has been used as an antimicrobial agent for almost 50 years, clinically and in consumer products, such as cosmetics, toothpaste, and plastics. Triclosan has multiple bacterial target sites for damage, depending on concentrations. Triclosan is bacteriostatic to prevent microbes from growing at low concentrations, by inhibiting an enzyme, involved in fatty acid synthesis. On the other-hand, triclosan is bactericidal, to kill microbes, directly, at higher concentrations, by destabilizing bacterial membranes, and also by introducing intercalating defects into a bacterial membrane. It can be incorporated by mixing into a resin system, before cure, melt mixed with thermoplastic-polymers, which set on cooling, into a solid, or alternatively applied as a coating, through several different methods (Petersen, 2014; NICNAS, 2009; Villaláu et al., 2001).

In general, the antibacterial products are marketed as an improved hygiene barrier. There is growing concern, however, regarding increased use of products, containing antimicrobial compounds, especially in the domestic sector. One of the reasons, behind the concern, is fear of development of antimicrobial resistance (Aiello et al., 2007; Gilbert & McBain, 2001, 2003; Levy, 2001), which is yet to be confirmed.

Furthermore, the results of this unfunded concise study (of preliminary nature), are largely relatively positive, providing a good starting point, for further and much deeper study, on the same. Next logical step, would be a detailed design, which can be generated, using 3D solid-modeling CAD programs, such as SolidWorks. Additionally, according to Ui et al. (2002), the emphasis of the design decisions, unavoidably shifts away from technology, towards the user interaction aspects, to cope with the new appreciations of consumers, for the aesthetic values of materials. Several studies, investigated the relation between materials and user interaction qualities, of products, and how users appraise materials. Selected studies also try to classify the visual and touch dimensions of different materials (see Smith et al., 2008) and, even, the sound dimensions, while in operation (see Ui et al., 2002).

Moreover, the current (conceptual) design is rather uncomplicated, hence, EDWDM was considered to be sufficient, during selection of the best design alternative. At a later (detail design stage) additional methods, such as: PuCC; AHP (Analytic Hierarchy Process); and TRIZ (Theory of Inventive Problem Solving) should be applied (see Starovoitova, 2019a; 2019b; Renzi et al., 2017; Starovoitova, 2016; 2015; Starovoitova et al., 2015, Mansor et al., 2014; 2013).

After selecting the most appropriate material, the further studies should also select the appropriate process, to manufacture the final set. A process is a method of shaping, finishing, or joining a material. The manufacturing processes fall into nine broad classes, process classes (Asby, 2010; Ashby &
Cebon, 2007) are: (i) Casting (sand, gravity, pressure, die, etc.); (ii) Pressure molding (direct, transfer, injection, etc.); (iii) Deformation processes (rolling, forging, drawing, etc.); (iv) Powder methods (slip cast, sinter, hot press, hip); (v) Special methods (CVD, electroform, lay-up, etc.); (vi) Machining (cut, turn, drill, mill, grind, etc.); (vii) Heat treatment (quench, temper, solution treat, age, etc.); (viii) Joining (bolt, rivet, weld, braze, adhesives); and (ix) Surface finish (polish, plate, anodize, paint). The following matrices and charts by Asby (2010) can be used, to select most appropriate-process: (a) The-Process-Material matrix; (b) The-Process-Shape matrix; (c) The-Process-Mass-range chart; (d) The-Process-Section-thickness chart; (e) The-Process-Tolerance chart; (f) The-Process-Surface-roughness chart; and (g) The-Process-Economic-batch-size chart.

5. Conclusion and Recommendations.
Poor-hygiene, during preparation and/or consumption of food, in-conjunction-with the-ability of food-borne pathogens to-survive (for a-long-time), and also to-multiply, rapidly, can-lead-to food-cross-contamination. Food-cross-contamination, in-turn, can-lead-to food-born-diseases, resulting in-some-cases, in: (a) severe-sickness, or even death (either immediately, or shortly, after food-consumption), or (b) in-increased-risk of chronic-diseases (e.g., Guillan-Barre-syndrome, or rheumatoid-arthritis (CAST)).

This study has accomplished all-its-objectives, by re-designing the-PRD and incorporating six-important-upgrading, to reduce food-cross-contamination, in the-new-product-design. The study, however, was purely conceptual in-nature; and, hence, it is further-recommends to: (1) carry-out a-detailed-design (by incorporating the-user-interaction-aspects and using more-advanced-methods, such-as PuCC; AHP, and TRIZ, in-selection of the-best-design-alternative); (2) select a-specific-material (out of the-group, identified by this-study, via Ashby-charts and matrixes); (3) choose a-mode of fabrication of the-set; (4) examine the-possibility of incorporating of AMCs; (5) fabricate the-prototype(s); (6) conduct explorative-use-ability-trial(s); and (7) analyze the-marketing-aspect of the-final-set.

This work is potentially-beneficial-to engineering-product-design students and faculty, as-well-as to households and food-establishments (subject-to successful-implementation).

6. Acknowledgement.
The-author wishes to-acknowledge Kepha Dickson and Yassin Keya, for their-commitment and valuable-contribution-to the-completion and success of this-concise-project, particularly during the-design-stage.

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