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A computational approach for creativity assessment of culinary products: the case of elBulli

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Abstract
In recent years, the gastronomy industry has increased the demand for rigorous and reliable tools to evaluate culinary creativity; but conceptually, creativity is difficult to define and even more difficult to measure. In this paper, we propose an AI-based method for assessing culinary product creativity by using the renowned high cuisine restaurant elBulli as a case study to understand the proliferation and scale of an entity's creativity and innovation. To achieve so, we trained a Random Forest Classifier to assess the level of creativity within the restaurant's recipes. The application of this model to elBulli's recipes allowed us to answer the following questions: how can creativity in a culinary product be characterized? Is there a single trait that is the key to culinary creativity? Is the creative culinary product a truly original outcome? Our key findings are (1) although ingredients and preparation techniques prove to be suitable attributes to characterize creativity in a recipe, none of them nor an elite subset clearly identifies creative cuisine, (2) new products are not radically novel with respect to previous creations, (3) creativity is more related to new uses and combinations of existing ingredients and techniques rather than to new ingredients or techniques. We believe that our method can find practical applications in supporting and guiding the creation of culinary products, identifying their strengths and weaknesses, and helping restaurants maintain a sustainable competitive advantage.

Keywords Creativity · Assessment · Culinary product · ElBulli · Recipe · Machine learning · Classification · Random forest

1 Introduction

Creativity has proven benefits for individuals and society in every sphere of life. It is a characteristic that fuels big ideas, brings innovative solutions to complex problems, and opens the door to new opportunities. Creativity can be seen both as an adaptation to evolutionary changes and as a force that contributes to change and evolution (Runco 2004). These changes affect people's lives both personally and professionally. A feature of contemporary society is that individuals have to adjust constantly to new and more complex problems, and creativity is what most often allows us to find innovative solutions to them. On the business front, research demonstrates that organizations compare favorably to others if new ideas are implemented (Prajogo 2006; Stonehouse and Minocha 2008). A noticeable characteristic of today's knowledge-based economy is that organizations operate in a highly competitive and global environment, requiring them to quickly match customer needs and requirements by continuously adding value to their products or services. Creativity offers potential value by adding quality and aesthetics to product features (Horn and Salvendy 2006).

It is commonly accepted that the greatest quality of creativity is this ability to promote novel solutions to solve difficult problems, allowing us to understand creativity as "the ability to form remote ideational associations to generate original and useful solutions to a given problem" (Atchley et al. 1999). Other scholars deepen the conceptual definition by affirming that the necessity between creativity and the problem is mutual—creativity is fundamental to solve a problem and a problem is essential to develop creativity. Thus, the solution to the problem and the creative activity are redefined as a result of a continuous and reflexive process (Basadur et al. 2000; Lubart 2001).

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In the case that concerns this paper, the main problem faced in the gastronomy industry is how to create new dishes and culinary products to maintain a competitive advantage. A now established highly competitive global culinary industry forces chefs to continuously create new dishes and culinary products as a means of establishing a competitive advantage over other restaurants (Suárez and Sancho-Caparrini 2013). These restaurants are the top representatives of the high-end cooking industry and, for that, they must demonstrate a high level of creativity (Messeni-Petruzzelli and Savino 2014; Svejenova et al. 2012) that is able to produce a sustainable competitive advantage (Chaston and Sadler-Smith 2012). In the world of haute cuisine, the competitive advantage is strongly based on the chefs' creativity and capacity to bring novelty to the market (Capdevila et al. 2015). This trend in the industry has led not only the gastronomy industry but also the broader restaurant sector to increasingly demand rigorous and reliable methods that can evaluate culinary creativity and the impact of this creativity (Horng and Lin 2009).

Comprehending the notion of creativity is key to maximally introduce novelty for product differentiation, but creativity still remains a "mysterious" (Jordanous 2012), "elusive" (Karpova et al. 2011), and complex concept that is very difficult to define and understand. This has made creativity researchers point out the need for broader outcome measures of creativity that can contribute to better develop our knowledge around creativity (Mayer 1999). The formulation of outcome measures is necessary to guide the understanding and enhancement of the creative process, as well as to refine the concept of creativity (Besemer and O'Quin 1987; Briskman 1980; Plucker and Renzulli 1999). This idea dates back to the days of Guilford, who can be considered the father of the modern creativity era in psychological research. Since his pioneering work, creativity has been viewed as a psychological dimension that is widely distributed in the general population and that can be developed and measured (Guilford 1950). Thus, the field of creativity research started with an ethos of measurement, which helped psychologists turn the "mysterious" creative capacity into something that people can identify, assess, and predict (Glăveanu 2014; Mayer 1999).

Today, the psychological dimension of creativity is still driven by psychometrics, for which creativity is a "mental trait" that can be quantified and defined by appropriate measurement instruments (Glăveanu 2014; Mayer 1999). However, if creativity is difficult to define, it is even more difficult to measure (Hennessey et al. 2011). In his work on creativity assessment, Ritchie (2001) stated "Evaluation highlights where progress is being made and how the evaluated item can be improved upon. Research progress can be demonstrated and tracked, and we can learn from achievements and weak points of a system." A crucial issue for creativity research and practical applications in the haute cuisine business is thus to properly assess creativity in order to support and guide its development, as well as contributing to the identification of strengths and weaknesses of creative culinary products. Current research also emphasizes the need for appropriate assessment methods for product creativity (Albert and Runco 1999; Christiaans 2002); but the lack of agreement on a precise definition of creativity deters researchers and organizations from developing better assessment methods that would allow them to understand the impact of product creativity (Horn and Salvendy 2006).

Despite the absence of a shared definition of creativity, researchers agree that it is an ability that involves the production of "novel, useful products" (Mumford 2003), "something original and worthwhile" (Sternberg 2011), or something "new and appropriate" (Barron and Sternberg 1988; Ochse 1990; Sternberg 1988; Sternberg and Lubart 1991, 1996). This emphasis on the outcome is a trait of the modern field of creativity, which has seen in the last two decades how the focus has gradually shifted from the creative person towards the creative product (Hennessey et al. 2011; Jordanous 2012; Ritchie 2001). Consequently, the new product-centered vision of creativity has caused an associated shift in assessment methods.

The present work follows this product-based trend to respond to the above-mentioned gastronomy industry's needs for creativity evaluation methods. Our proposed solution is a computational method for identifying, assessing, and predicting creativity in culinary products. We evaluated our method by applying it to elBulli's creations. elBulli was a restaurant well-known for its commitment to creativity. The renowned restaurant was the recipient of three Michelin stars and five Best Restaurant in the World awards by Restaurant Magazine (Williams 2012). In 2011, it became a foundation whose values of creativity and innovation have been adopted from the former restaurant. By evaluating the creativity of elBulli's creations, we aim to answer the following questions:

1. How can creativity in the product be characterized? According to the product-based approach, product creativity is a quantifiable variable whose value is directly related to differences in levels of specific attributes or characteristics of the product. Therefore, differences in the quantities of product attributes produce differences in levels of product creativity (Horn and Salvendy 2006). What are these attributes in elBulli's culinary creations?
2. Is there a single trait that is the key to creativity? From the identified attributes that characterize elBulli's products, are there any subset of attributes and/or do they take specific values that are exclusive of creativity? Can

product creativity at elBulli be unequivocally defined by a particular set of attributes and a range of values?

3. Is the creative product truly an original outcome of the creative person and the creative process? It is accepted that knowledge and experience are key features that guide both the individual creator (Csíkszentmihályi 1997, 2006) and the appropriate observer evaluating creativity (Amabile 1982). How much of this previous knowledge and experience is embedded in new products? In other words, how radically novel can new products be? Is there an inherent threshold to define optimal creativity? Do elBulli's new creations resemble its preceding creations, and if so, to what extent?

This paper attempts to make three contributions to the field of culinary creativity. The first is an accurate computer-based method for assessing product creativity. The method is a machine learning model, as described below, that can help professionals of the gastronomy industry and creativity practitioners identify weaknesses and strengths of culinary products. The second is a better understanding of the concept of creativity and its assessment, by two means: (a) a compilation of creativity definitions and assessment methods, and (b) answering the research questions mentioned above. The third contribution is a methodological framework for handling analogous case studies in other areas. These issues are addressed in the rest of the paper, which is structured in the following sections: Sect. 2 presents an overview of creativity and assessment methods; Sect. 3 justifies the need for our own assessment technique; Sect. 4 describes the case study and its relevance for this analysis; Sects. 5 and 6 detail the methodology of experiment and the results; and Sect. 7 presents the conclusions of this work and outlines future research lines.

2 Literature review

This section introduces an exhaustive overview of creativity literature and, more importantly, reconciles the many theoretical frameworks that scholars and researchers contributed to the field to make sense of the experimental part of this article.

2.1 The conceptualization of creativity

The interest and importance of creativity as a discipline are evident from the increasing amount of research focused on the topic in the last years. Although the term creativity can be found in writings as early as those of ancient Greece and Rome, it was not systematically employed before the mid-twentieth century (Treffinger et al. 2002). The field of creativity as it exists today has its roots at that time, as a result of the pioneering work of Guilford (1950), Rhodes (1961), and Torrance (1962), among other contemporary leaders that provided the foundation that has influenced more than 6 decades of theory, research, and practice. Since then, countless definitions and models of creativity have been put forward, but due to creativity's complex nature, none of them has been universally accepted. Defining creativity is indeed a research topic per se (Lubart et al. 2003). As an illustration, Treffinger (1995) compiled more than a hundred different definitions from the literature and as many techniques to assess it (Treffinger et al. 2002). The different assessment methods rely upon the specific aspects of each definition.

From early in the modern era, researchers in psychology have studied creativity from three distinctive standpoints: person, process, and product (Cropley 2009). Rhodes' definition of creativity (1961) added a fourth one: the press (i.e., the pressure exerted by the environment). According to Rhodes, creativity is a phenomenon whereby a person communicates a new product, and where the mental process and the environment are implicit. The result of this addition was a model that formalized the four P dimensions (or the four Ps) of creativity (person, process, product, and press), one of the most widely cited in the literature. The four Ps are more than a conceptual typology: they are units of analysis for creativity researchers (Glăveanu 2014), who have normally focused primarily on one of them (although none of the units or dimensions is independent of the others). Vidal (2009) presents a comprehensive review of the main publications related to the four Ps, with a special emphasis on problem-solving, and unlike other authors, he also considers a fifth aspect: learning and cognition. The five dimensions of creativity are described below along with some of their most relevant works.

2.1.1 Learning and cognition

Creative learning and cognition are abilities related to the human brain's physiology of thinking, especially when they are applied to solving problems. Creative learning is a natural human process that occurs when people become curious about knowing more or when they face a problem with no known or learned solution. The different forms of cognition and creativity are related to the brain's structure and function, which are competencies of neuropsychology, a research area that has further increased its contribution to the understanding of individual creativity (Vidal 2009).

2.1.2 Process

A large number of authors in the field of psychology have focused on the study of the creative process. From a problem-solving perspective, the process is the way in which a problem is solved, and it may entail a new way of seeing, a

different point of view, an original idea, or a new relationship between previously known ideas (Vidal 2009). Lubart (2001) provides an outcome-oriented sense of the creative process and defines it as "the sequence of thoughts and actions that leads to novel, adaptive productions." The author provides a comprehensive revision of the concept, with particular emphasis on variants derived from Wallas' four-stage model, in which he suggested that any creative process consists of four stages: preparation, incubation, inspiration, and evaluation (Wallas 1926). The sequentiality of Wallas' model matches the classical Schumpeterian linear model of innovation, first published in 1912 (Schumpeter 1934), that distinguishes between a phase of creativity (searching for ideas), a phase of invention (of innovative products), and a phase of diffusion (transfer of innovative products to the market). Innovation is understood as the implementation of a solution whose origin is a creative idea with the purpose of solving a problem (Jimenez-Mavillard 2016). The implemented solution requires its acceptance by people other than the creator of the idea (Amabile 1996; George 2007; Zaltman et al. 1973), which implies that creativity is a necessary precursor to innovation (Stierand et al. 2014).

Sequential models contrast with the more recent school of cyclical/iterative processes that lead to creative products. These processes contribute to exploring ideas in greater depth, to end up breaking the previous rules and establishing new ones. In such a context, the creative process has two phases, the phase of creativity (ideation process) and the phase of innovation (transfer process), that run in parallel with coupling and decoupling interactions. There is no linear process of innovation nor a sequence of distinct phases, but a continuous feedback loop between the creative and innovative phases (Capdevila et al. 2015).

Guilford (1950) underlined the currency and validity of Wallas' model, noting the "considerable agreement that the complete creative act involves four important steps." However, he also emphasized the importance of any mental operations for the creative process. Examples of such cognitive operations are divergent and convergent thinking. The main principles in creative problem-solving processes include starting with divergent thinking to generate as many ideas or solutions as possible and then switching to convergent thinking to subsequently select the most promising ones (Vidal 2009). This interest in mental operations happening within individuals' creative minds caused the proliferation of numerous psychological discussions on the creative person.

2.1.3 Person

Discussions on the creative person have been summarized by Eysenck (1993) and Helson (1999), among others. According to Sternberg and Lubart (1991), creative people are intuitive individuals able to predict what ideas and products will succeed. It is widely acknowledged that the person's creative ability is the single most important factor contributing to innovative outputs in the creation process (Althuizen 2012; Kabanoff and Rossiter 1994). The creative ability involves diverse factors that can be classified in different categories: (a) personal traits such as openness (Kaufmann 2003), personality, intelligence, thinking style (Sternberg 2006; Sternberg and Lubart 1992, 1995), genetic makeup, talent (Csíkszentmihályi 1997, 2006), experience, and knowledge of the field (Csíkszentmihályi 1997, 2006; Sternberg 2006; Sternberg and Lubart 1992, 1995); (b) motivation (Helson 1999; Kaufmann 2003; Sternberg 2006; Sternberg and Lubart 1992, 1995); (c) resilience (Helson 1999); (d) emotions[1] like positive or negative feelings associated with creativity (Kaufmann 2003), reward, and satisfaction (Csíkszentmihályi 1997, 2006). For example, Heller (1954) considers that the relationship between the creator and the creation is significantly analogous to the emotion experienced by the artist facing their artistic work. Emotions can also be experienced by the recipient—the creator can make the recipient feel a positive affect, an emotional impact and identity with the creation (Horn and Salvendy 2006); and (e) problem solving, they are, fluency, flexibility, originality, and elaboration (Vidal 2009). In his paper "Creativity for problem solvers", Vidal presents these four key abilities that characterize creative individuals as well as some approaches from the interdisciplinary field creativity and participative problem-solving. Vidal affirms that these abilities can be trained and enhanced with the aid of some tools, specifically those suitable for group work, like brainstorming, question checklists, novel ideas, and mind maps. The author demonstrates the usefulness of these methods in real-life problem-solving scenarios, such as strategy development, design of decision-support systems for complex problems, and creative optimization in organizations.

2.1.4 Press

As well as a mental process and tangible actions, creativity is also a cultural and social activity. In 1982, the psychologist Teresa Amabile introduced her socio-cultural model of creativity, under which a product or idea is not creative simply because it was created by a creative person or because it was the outcome of a creative process: a product or idea is creative if a group of experts independently agree that it is creative. Thus, she claims that creativity research will always

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be attached to the criterion of social appropriateness. Amabile's model is extensively used in psychology, for example, by Csíkszentmihályi (2002, 2006) and Gardner (2008). Csíkszentmihályi (1997, 2006) further developed these ideas and introduced his systems theory. He, among others, argues that creativity emerges as the result of complex interactions between three sources: (1) the creator, as theorized above, (2) the domain, which encapsulates the cultural and historical context, where the individual develops the creative activity under specific rules, practices and values, and (3) the field of expertise, where expert individuals, institutions, or society at large evaluate the creative accomplishments of the creator. The creator's ability is what Csíkszentmihályi calls "creativity with small c" as opposed to "creativity with capital C", represented by the domain and the field. The two latter sources—domain and field—form the environment (or "press" in Rhodes' terminology).

2.1.5 Product

The last of the four Ps has centered the most attention in the field of creativity for the last decades (Hennessey et al. 2011; Jordanous 2012; Ritchie 2001). Rhodes (1961) suggested that the product approach begins with the product, then the person, process, and press, meaning that addressing the outcome is the first step to truly understanding the whole creativity procedure.

In spite of the fact that the definition of creativity has been a matter of disagreement among psychologists (Amabile 1996) and approaches to defining creativity vary in important ways (Barron and Harrington 1981), it is safe to assume that one of the most stable formulations of what being creative means is the product-based definition. First, the term product is broadly used to include both abstract ideas and tangible objects (Mayer 1999; O'Quin and Besemer 2006; Woodman et al. 1993), and second, there are two core elements that characterize creative ideas or products: novelty and usefulness, although each author uses their own terminology to refer them. A revision of some emblematic definitions is featured below.

A product is said to be creative if it is: novel and useful (Mumford 2003; Stein 1953); original and relevant (Taylor 1975); new and appropriate (i.e., useful and socially valued) (Amabile 1982, 1983, 1996; Barron and Sternberg 1988; Brown 1989; Lubart 1994; Ochse 1990; Sternberg 1988; Sternberg and Lubart 1991, 1995, 1996); novel, resolute (i.e., useful and valuable), and stylish (i.e., elegant and well-crafted) (Besemer and O'Quin 1987; O'Quin and Besemer 2006); novel and socially valued (Mumford and Gustafson 1988; Redmond et al. 1993); original and useful (Atchley et al. 1999); original and practical (Runco and Pritzker 1999); novel, appropriate, and non-algorithmic (Mayer 1999); new (Hasse 2001); novel, relevant, and effective (Cropley and Cropley 2005); original and appropriate (Horn and Salvendy 2006); novel (Cropley 2009) original and worthwhile (Sternberg 2011) novel, relevant/effective (i.e., useful), elegant, and genetic (i.e., transferable) (Cropley and Kaufman 2013).

Attributes like style and relevance are reminiscent of Jackson and Messick's (1965) distinction between internal (e.g., the product is aesthetic, pleasing) and external (e.g., the product is relevant, useful) criteria. While both criteria coexist in most definitions of creativity, some authors lean more towards one of them. Among the authors inclined towards internal criteria, we find Taylor (1975), whose conceptualization of creativity is based on six features: generation (product's potential to generate new ideas), reformulation (changes introduced by the product), originality (product's novelty), relevancy (product's usefulness), hedonics (product's aesthetics), complexity (product's degree of completeness, adequacy, comprehensiveness, and universality), and condensation (product's degree of simplification, unification, and integration).

On the other side of the spectrum, some authors have emphasized the beneficial and social components of the creative product. For example, Atchley et al. (1999) have highlighted the creative product's problem-solving goal, while Amabile (1982) or Redmond et al. (1993) have underlined its social validity. Teresa Amabile's definition of product creativity is one of the most accepted and extensively used: "A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated." MacKinnon (1968) proposed five balanced internal and external criteria of product creativity: originality, adaptiveness (the product solves a problem), elegance and other aesthetic qualities, transcendence (it transforms reality), and realization (its development and communication to others). The approach of the present work rests on MacKinnon's definition.

2.2 Assessment methods

From the 60s, the area of creativity has seen a progressive increase in both the definition of the concept and the development of measures and assessment techniques. The major works that strongly influenced the field are centered on the creative person (Guilford 1967; Torrance 1974; Wallach and Kogan 1965). These and the vast majority of the experimental work on the field have relied upon creativity tests that are similar to conventional intelligence tests (Amabile 1982). Guilford (1950) put the emphasis on divergent thinking as an essential part for creativity. This mental operation "allows generating numerous ideas, enables the individual to consider alternative pathways of research, thus increasing the probability of finding an original and adapted idea" (Barbot

et al. 2011). Divergent thinking tests such as Wallach and Kogan tests (1965), the uses of objects task (Guilford and Hoepfner 1966) and the Torrance tests of creative thinking (TTCT) (Torrance 1974) are standardized tests that evaluate the capacity of the individual to generate many ideas in a limited amount of time, starting from a simple idea. TTCT still remains widely used in assessments of creative talent for individuals.

With the transition from the person-centered to the product-based vision of creativity in the last decades, assessment methods have gradually shifted to measuring creativity in the product rather than in the person or in the process. MacKinnon (1978) and later Amabile (1983) argued that measuring creativity is difficult when the start point is the creator or the creative activity themselves; however, from an empiric and conductist perspective, it is possible to observe creativity in the product created. This is the approach that we adopted in this work. Rhodes (1961) suggested that addressing the outcome is the first step to understand the entire creativity process. Briskman (1980) proposed that creative processes and persons depend on the product or outcome evaluation. Ritchie (2001) argues that humans normally judge the creativity of others by what they produce, because one cannot easily observe the underlying process of human creativity. Horn and Salvendy (2006) attempted to understand how creativity is reflected in products. They chose this approach because "creativity is generally associated with the judgment of a product, such as thoughts, writing, art, or inventions." More recently, Cropley and Kaufman stated that the ability to characterize the creativity of products is key to utilizing creativity (2013).

In the same way that divergent thinking tests are the most used method for measuring creativity in individuals, judge-based evaluation is the common option for assessing product creativity. Two major judge-based approaches were developed during the person-to-product transition period: subjective assessments and rating scales (Horn and Salvendy 2006), which have two main representative instances: the extensively used consensual assessment technique (CAT) (Amabile 1982) and the creative product semantic scale (CPSS) (Besemer and O'Quin 1987), respectively.

CAT was proposed by Teresa Amabile in 1982 as a central methodological companion to her 'social psychology of creativity', and is grounded in her original definition of creativity: "a product or response is creative to the extent that appropriate observers independently agree it is creative." CAT rests on three important assumptions: first, that appropriate observers ("those familiar with the domain in which the product was created or the response articulated") can produce reliable judgments of product creativity; second, that creativity in a product can be identified when seen and that no universal criterion is needed; and third, that there exist degrees of creativity and that the appropriate judges can agree that a product is more or less creative than another. CAT is subjective because of the raters' previous knowledge and experience, and also due to the context in which the rating is occurring.

CAT is typically used for artistic work, such as collages (Amabile 1996; Hennessey et al. 2008), short stories and poetry (Baer et al. 2004, 2009; Kaufman et al. 2005), photography (Dollinger 2007; Kaufman et al. 2007), design (Haller et al. 2010), music compositions (Hickey 2001), and culinary creations (Horng and Lin 2009).

CPSS is based on a theoretical model that conceptualizes three categories of product attributes: novelty, resolution, and style; and defines 55 attribute pairs, each answered on a seven-point response scale. This technique asks raters to evaluate broadly rather than closely the specifics of the product under consideration, so that it is a generic method applicable to a wide range of products. CPSS has extensively been used in business, for example, to examine the creativity of marketing programs, to predict willingness to buy, to improve product design, to examine the effectiveness of advertisements and the processes used by project managers, or to create product profiles to assist in identifying both weaknesses and strengths of products (O'Quin and Besemer 2006). Other scale-based techniques are creative product inventory (Taylor 1975), which measured the dimensions generation, reformulation, originality, relevancy, hedonics, complexity, and condensation; student product assessment form (Reis and Renzulli 1991); and creative solution diagnosis scale (Cropley and Kaufman 2013), that breaks creativity down into four factors—novelty, relevance/effectiveness, elegance, and genesis—and 27 individual items. The purpose of these classifications is to be used as indicators of the type and level of creativity that a product possesses and, unlike CAT, to provide guidance to evaluators and improve their judgements.

The next section justifies why despite the variety of methods to measure creativity, none of them meets our needs.

3 Justification

The methods presented in the previous section are generic assessment techniques that have multiple applications. However, we found that not many works have been done on creativity of culinary products, and we could not find a suitable existing method to apply to our case study: elBulli. Some recent works on culinary creativity and the reasons for their unsuitability for our case are described below.

Horng and Hu (2009) looked at the relation between chefs' creative process and their creative products. Well grounded in Wallas' model (1926), this work is focused on understanding and extending the creative process rather than

providing methods for assessing creativity in the culinary product.

Horng and Lin (2009) developed a scale for evaluating creative culinary products based on CAT (Amabile 1982). As already said, evaluating product creativity is a complex task that has typically been performed by people, either by completing creativity tests or by agreement of domain experts (Amabile 1982). Nevertheless, using human judgement to evaluate creativity has some disadvantages. First, tests scored by humans introduce subjectivity and individual variance into the scores (Forster and Dunbar 2009). Second, the perception of creativity can be sensitive to time and current societal context (Boden 1994), so what is considered creative by a person might not be perceived as creative by the same person in a different situation. Third, human raters can say whether they think something is creative but may not be able to give a reasoned explanation of their decision (Jordanous 2012). Fourth, human opinion is variable—two raters may not agree on what they find creative (Cardoso et al. 2009; Widmer et al. 2009). This could even be aggravated by judges' own knowledge and expertise. Fifth, time and resources are needed to run suitable experiments, including a large number of participants that does not guarantee that, after time and resource consumption, a consensus can be reached (Jordanous 2012).

Our proposed alternative to a human-based solution is a computational approach that automates the assessment process, avoids the human component, and meets Ritchie's (2001) requirements for any evaluation process: clearly stated, transparent, and repeatable. Two recent works following a computer-based solution are described next.

Forster and Dunbar (2009) created a test where a group of participants had to provide creative uses for a set of different objects, and then applied latent semantic analysis (LSA) (Deerwester et al. 1990; Landauer et al. 1998), a tool used to measure semantic distance between words, to score the originality of the responses provided by the participants. The authors claimed that LSA produced a better model of the underlying semantic originality of responses than traditional measures. Although this idea could be applied in the context of the culinary world, this method is meant to test the creativity of the person, not of the product.

Wen et al. (2015) proposed a measure to rank how classic or modern a recipe is. Their method could fit our needs as the recipe is a form of culinary outcome and the notions of classicism and modernism can be easily adapted to the idea of creativity. However, this score is limited to the ingredient composition, while creativity in cuisine is not based only on ingredients, but it is closely related to the search for new ingredients, new techniques, and/or new uses and combinations of them (Capdevila et al. 2015; Domene-Danés 2013). Also, in computational creativity, where flavor is key for culinary recipes (Cromwell et al. 2015; Pinel and Varshney 2014; Shao et al. 2014; Varshney et al. 2013), the flavor of a dish owes as much to the preparation technique as to the choice of particular ingredients (Ahn et al. 2011; McGee 2004; This 2006, 2009). Therefore, any new and improved method of assessment must be based at least on both ingredients and cooking techniques.

The literature review of product creativity measurement methods, theory, and examples reveals two major points to meet the gastronomy industry's demand for rigorous and reliable creativity evaluation techniques: (1) the need for more valid, applicable, and predictive measures of culinary product creativity, in general, and (2) the lack of measures of recipe creativity based on ingredients and techniques, in particular. In this absence, we did what has been a usual practice in the field of creativity for the last decades: providing our own assessment method (detailed in Sect. 5). The next section describes the case study and justifies the interest in this work.

4 Case study: elBulli

ElBulli was a renowned Spanish restaurant specialized in high cuisine that received three Michelin stars and was awarded Best Restaurant in the World by Restaurant Magazine for 5 years (Williams 2012) during its 50 years of life (1961–2011). The restaurant owed its success to Ferran Adrià's, its chef and co-owner, revolutionary gastronomic vision and commitment to creativity and innovation.

The practice of creativity at elBulli makes it an appropriate case to answer the research questions raised in Sect. 1. In short, we aim to understand how the use of ingredients and cooking techniques affects product creativity. A case study approach is advised when the focus of the study is to answer how type of questions (Yin 2003). Our case study falls into two categories according to two classic classifications: (1) it is explanatory (Yin 2003) because it seeks to explain the presumed causal links between ingredients and techniques on one hand, and culinary product creativity on the other, (2) it is intrinsic (Stake 1995) because of its particular interest and uniqueness, which respond to its singular inner processes that redefined itself over time: evolution and reinvention, diffusion of its practices (Jimenez-Mavillard and Suarez 2020), creation of new concepts and techniques and their dissemination across time and social space, especially between Spain and USA (Opazo 2012). Indeed, elBulli and Ferran Adrià generated high expectation in media and within the academic community, which has studied the phenomenon from many diverse disciplines such as food studies, business and management, or creativity and innovation (e.g., Capdevila et al. 2015; Cassarino 2014; Domene-Danés 2013; Jimenez-Mavillard 2016; Opazo 2012; Polan 2011; Stierand et al. 2014; Suárez and Sancho-Caparrini

2013; Svejenova et al. 2007, 2010). Therefore, the goal of this work is not to understand a generic phenomenon or to build a theory—although we expect to apply our findings to analogous cases, as detailed in the conclusions and future work section—but to analyze creativity at this exemplary restaurant for its own sake.

ElBulli's creativity can be explored from every of Rhodes' four dimensions (1961). Centered on the person, some authors have addressed Adrià's creativity (e.g., Svejenova et al. 2007, 2010). The chef made creativity the cornerstone of his practice and his main issue was to make it sustainable and evolving in the long run (Suárez and Sancho-Caparrini 2013). His commitment to be creative and to make creativity the core of his activity is consistent with the investment theory of creativity that sees this as a decision and, therefore, it can be trained and developed (Colangelo and Davis 1991; Florida 2002; Fontenot 1993; Guilford 1950; Michalko 2006; O'Hara and Sternberg 2001; Osborn 1963; Sternberg 2006; Sternberg and Lubart 1991, 1996).

Regarding the process dimension, a specific process of creativity was undertaken by elBulli's creative team: the team started by breaking the previous rules of cooking imposed by the dominant school, French nouvelle cuisine; new rules were established and enunciated through a manifesto; new ingredients, processes and techniques were invented; a new grammar of usage—also called codebook—was completed; the new codebook was progressively adopted through a diffusion and institutionalization process (Rao et al. 2003); new dishes were conceived and proposed, during the innovation phase, for the menu at the restaurant.

The described process occurred in a cyclical workflow. Stierand et al. (2014) see creativity and innovation in high cuisine as a systemic rather than sequential developmental process: ideas emerge during the creativity phase and are put into practice in the innovation phase; external agents evaluate the goodness of the proposed solution and the loop repeats until a satisfactory solution is reached. In this context, elBulli's creativity and innovation processes run in parallel with coupling and decoupling interactions. Creativity contributed to the realization of new innovative dishes, and in turn, from the daily practices when serving new dishes in the restaurant, new ideas were transferred to nourish the creative process (Capdevila et al. 2015).

The environmental pressure (press) played an important role in the process interactions: Adrià implemented the iterative cycle between creativity and innovation in two dimensions: temporal (summer vs. winter season) and spatial (restaurant vs. taller—Spanish word for workshop) (see Table 1). This new organizational and functional structure led to an implementation in separate environments of the two processes described in the *geneplore* (generative and exploratory) model of creativity (Finke et al. 1996).

Table 1 Systemic developmental process of creativity and innovation

Temporal/spatial	Workshop	Restaurant
Winter	Search/research/exploration/ideation/creation	–
Summer	–	Production/exploitation/generation/transfer/innovation

Adrià sought innovation outside the field of gastronomy—cooking can be seen as natural lens to explore and construct a common language to engage in interdisciplinary collaboration between different disciplines and working environments (Chornyak 2014)—and the workshop brought together a committed multidisciplinary team of chefs, scientists, and designers. This willingness to bridge science and cooking explains why Adrià and his team started their creative approach by bringing ideas in from a variety of domains, and gathering, analyzing, synthesizing, contrasting, and mixing ideas and concepts to create new ones. This phase included gathering and classifying all ingredients and techniques used in cooking, and the scientific interpretation for the main reactions. This intense effort of classification helped them to discover the potential of a wide range of products[2] that can be used in a diversity of preparations (Capdevila et al. 2015). Then the team would invent new ideas through a disciplined trial-and-error process (Svejenova et al. 2010), but they would not merely rework established recipes, which offered limited scope for further innovation—recipes are a sort of algorithm that explicitly gives a set of instructions to reproduce existing culinary knowledge. Rather, the focus of the new method of creative cuisine was anchored at the lower levels of preparation, techniques and concepts. It is at these levels where creative activity in the kitchen may become evolving creativity (Suárez and Sancho-Caparrini 2013), as their broader range of combinations enables numerous turnings leading towards potential variations or "fluctuations" that constitute "a repository of unique innovations" (Ciborra 2009). The lower levels are the "grass roots" of the creative method, and by emerging from there, the new creations were deeply entrenched with elBulli's culture in a way that they were difficult to imitate and, therefore, helped to successfully maintain the competitive advantage over other restaurants (Ciborra 2009).

[2] The general meaning of the term *product* used in this paper is "a final outcome or result of a process", "something produced". Nonetheless, the term *product* referring to this footnote is an intermediate outcome, yet closer to an ingredient than to a final result. In elBulli's language, a product is the result of applying cooking techniques to ingredients; but it is not a final result per se.

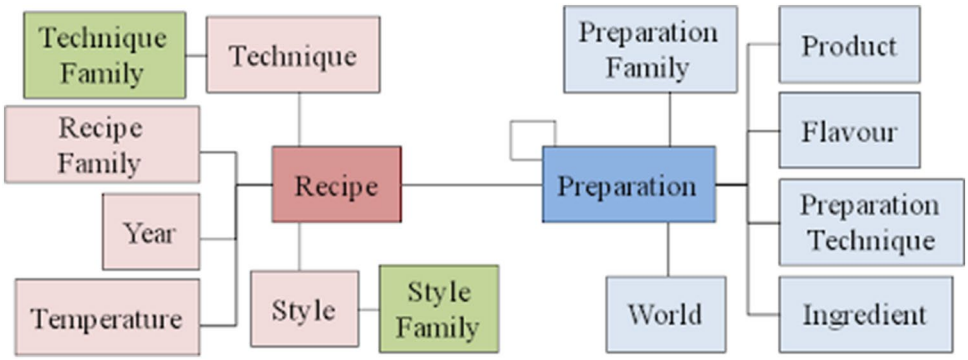


Fig. 1 Schema of elBulli's codified language (Suárez and Sancho-Caparrini 2013)

Evolving and sustainable creativity was possible thanks to two factors. First, the practice of creativity gave rise to an emerging vocabulary that, after being formalized in 2002, resulted in a codified culinary language (see Fig. 1) that would be the base to guide the creative method of elBulli from that moment onward (Suárez and Sancho-Caparrini 2013). Second, the above-mentioned shift in focus from the recipe to the preparation empowered the reuse of ideas and previous work, which enabled sustainability in the long term. A preparation is the result of applying cooking techniques to products[3] or ingredients to obtain a conceptually finished result. Preparations, in turn, could be final preparations themselves—ready to be incorporated into a recipe—or be part of more complex preparations. A recipe is a combination of preparations. This distinction between intermediary and final preparations in a two-step classification introduces a level of transformative power into the sustainable dimension of a method of creativity that constantly evolves (Suárez and Sancho-Caparrini 2013). The ability to consider a preparation as a product[4] in use for other preparations (see the arc from Preparation to itself in Fig. 1) provides a powerful tool to elBulli's language, whose elements can be reused, replaced, and reassembled as interchangeable parts of a mechanism composed of pieces. This unique codified language[5] turned into the core of elBulli's creative model.

Finally, with respect to the product dimension, despite the numerous studies that have addressed creativity at elBulli, no previous research has been done on creativity assessment methods for its culinary production. To the best of our knowledge, only Jimenez-Mavillard (2016) proposed a first machine-learning-based approach to the matter. The next section details the solution adopted in this work.

5 Methodology

To answer the question "*how* the use of ingredients and cooking techniques affects the level of creativity in elBulli's culinary products?", we include specific propositions to place limits on the scope of the study and increase the feasibility of completing the analysis (Baxter and Jack 2008).

Proposition 1 *elBulli's recipes are creative. This proposition can be assumed by the following triangulation*:

1. *By consensual assessment, that is, it is socially accepted by academic researchers and food critics.*
2. *Because they are the result of a creative process (geneplore) conducted by a creative person (Ferran Adrià) in a suitable environment (the restaurant and the workshop). It is proven that the quality—a fundamental attribute of creativity (Horn and Salvendy 2006; MacKinnon 1968)—of new products or services heavily depends on the creative performance of individuals working alone or in teams (Kristensson and Norlander 2003). Besides, the implementation of the coupling and decoupling cycles of creativity through the geneplore model (see Table 1) led to creative products (Lubart 2001).*
3. *They fit MacKinnon's definition of creativity.*

Proposition 2 *It is possible to observe and measure creativity in the product (Amabile 1983; MacKinnon 1978).*

Proposition 3 *Creativity of culinary recipes is closely related to their ingredients and preparation techniques (Ahn et al. 2011; Capdevila et al. 2015; Domene-Danés 2013; McGee 2004; This 2006, 2009).*

[3] Idem.

[4] Idem. The term *product* acquires the general meaning again in the following uses from now on.

[5] Although the academic literature agrees that elBulli created its own culinary language (e.g., Cassarino 2014; Svejenova et al. 2010; Suárez and Sancho-Caparrini 2013), studying this language from a formal theoretical framework is out of the scope of this paper. Instead, we are analyzing the vocabulary encoded in elBulli's menu, which constitutes itself a cultural artifact, as inferred in Sect. 5.

The next step is narrowing down the notion of product and staying within a definition of creativity. The most natural culinary product to analyze would be a dish; however, the restaurant closed in 2011 and the only way to experiment with its dishes would be recreating them from their recipes. To do so, we would need a team of professional chefs and a professional kitchen for them to prepare the dishes, which would not be feasible. Instead, we analyzed the language encoded in the recipes of elBulli's menu, since recipes are written faithful representations of the actual dishes. Recipes are also suitable subjects of analysis because they are a form of externalized knowledge (Nonaka and Takeuchi 1995) and, therefore, they are observable and quantifiable—for example, the above-mentioned ranking of recipes from classic to modern by Wen et al. (2015).

Not only is the recipe an appropriate subject of analysis for its convenience to be measured, but for its interest as a cultural artifact. The recipe is the basic method of dish transmission for traditional cuisine (Suárez and Sancho-Caparrini 2013). When cooking led to the birth of oral and written guidelines, the transmission of recipes allowed food to acquire its own language and grow into a complex cultural product shaped by climate, geography, the pursuit of pleasure, and later, the desire for health (Montanari 2006). Since the inception of written cooking directions, gastronomy has been a field where new developments have always been codified in the form of recipes and cookbooks (Capdevila et al. 2015). A clear evidence of the significance of written guidelines is the consolidation of the culinary discipline in the nineteenth century in France thanks to the production of written texts (Ferguson 1998, 2004).

Writing and authoring new recipes has also high importance for chefs. First, written recipes represent externalized knowledge (Nonaka and Takeuchi 1995) that can be easily transferred geographically, increasing the chef's international influence (Capdevila et al. 2015). Second, writing recipes guarantees chefs the authorship of the novelty, which is essential in an area where the intellectual property system is based on social norms and not on legal intellectual property rights, like grants, patents or copyrights (Fauchart and von Hippel 2008). Recognized authorship reinforces the chefs' fame among peers and public.

Regarding the definition of creativity, we chose Donald MacKinnon's (1968). He proposed five criteria of product creativity: novelty, adaptiveness, style, transcendence, and realization. elBulli's recipes fit perfectly this definition:

- Realization: it refers to the development of the product and the communication to others. Adrià developed a creative method, which he communicated in an effective manner. Proof of this effective communication is the renown that Adrià gained by publishing his results in international conferences, books, and journal articles, in a way similar to the peer review academic process (Williams 2012). His case is exceptional, though: while many others have embarked on writing and publishing, his books are unique in that they do not only include recipes—rather, they discuss issues such as philosophy, creativity, and organization in cuisine, as a vehicle for spreading elBulli's culinary language (Svejenova et al. 2010).
- Transcendence: it means transforming reality. Transcendence at elBulli went beyond transforming raw materials into cooked food. Adrià deconstructed ingredients by transforming their texture, shape, and temperature, and at the same time, respecting their original harmony (De-Solier 2010). Moreover, the holistic, performative, aesthetic, emotional and sensory experience of dining at elBulli "confuse[d] and transform[ed] human perception" of food (Domene-Danés 2013).
- Style: its elegance and other aesthetic quality. Adrià and his team, indeed, developed and implemented a method to achieve the objective of a truly creative form of culinary art (Horng and Lin 2009) that led to a wider variety of dishes, as well as more innovative, both aesthetically and culturally (Suárez and Sancho-Caparrini 2013).
- Adaptiveness: it is the ability of the product to solve a problem (that is, the product is said to be useful). The central problem at elBulli was how to make creativity sustainable in order to maintain the competitive advantage of the restaurant. The aforementioned change of focus from the recipe to the preparation propelled the reuse of ideas and previous work, which in turn enabled evolving and sustainable creativity that gave rise to a greater amount of preparations and recipes in elBulli's catalogue. The variety of new dishes allowed Adrià to completely renovate the menu every year, which contributed to maintaining the competitive advantage over other restaurants (Suárez and Sancho-Caparrini 2013).
- Novelty. The novelty of elBulli's recipes was granted by two facts: the menu was completely renovated every season and within the season, and the creative method led to more and more innovative dishes (Suárez and Sancho-Caparrini 2013).

Novelty is, along with usefulness (or adaptiveness in MacKinnon's terminology), the most relevant criteria according to numerous authors (read the compilation of product creativity criteria in Sect. 2), especially in the world of high cuisine, where the competitive advantage strongly depends on the chefs' creativity and capacity to bring novelty to the market (Capdevila et al. 2015). For this reason, we entrusted the creativity value of elBulli's recipes to their novelty, which in turn changes over time according to the composition of ingredients and techniques. The patterns of novelty dependence on ingredients and techniques were

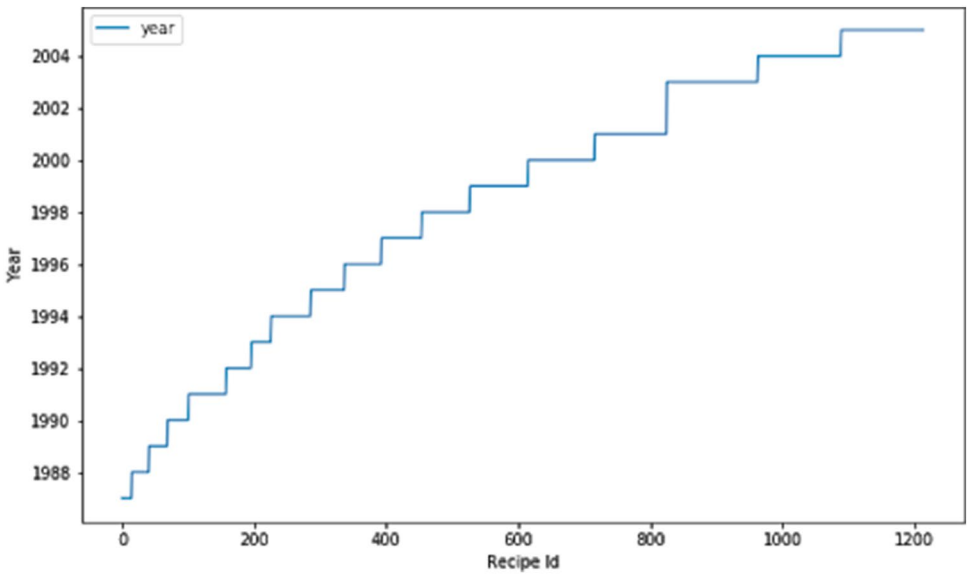


Fig. 2 Recipe ids (1-1214) and creation years (1987–2005)

inferred by applying machine learning to the dataset of recipes (Jimenez-Mavillard and Suarez 2020). The result of this inference process was a Random Forest classifier, whose construction is detailed as follows.

5.1 Data

The present experiment lays on secondary data: a collection of recipes gathered from elBulli's General Catalogue ("elBulli 1983–2011 General Catalogue" n.d.: http://www.elbulli.com/catalogo/catalogo/index.php?lang=en). The catalogue was gradually published in books (Adrià et al. 2005a, b, c, 2006a, b, 2014) that included DVDs with the menus of the corresponding seasons. We gathered all the recipes created in the period 1987–2005. This time range is truly significant in the history of the restaurant: 1987 means the beginning of the consolidation and mastering of the main techniques in high cuisine by Adrià and the team, while 2005 is the end of a period that entailed the explosion of creativity and systematization of a method to make creativity evolve and sustainable (Suárez and Sancho-Caparrini 2013).

The recipe data was extracted from the DVDs corresponding to the period 1987–2005 and then was parsed with Python[6] and NLTK,[7] and manipulated with Pandas.[8] Each recipe contains a unique identifier, its title, creation year, and the preparations that compose it. Each preparation contains, in turn, its own title, a list of ingredients and cooking instructions. We parsed the cooking instructions to extract the list of techniques for every recipe. During this period, the restaurant created 1214 recipes, used 2130 unique ingredients and 235 different cooking techniques.

5.2 Classification models

Based on the following propositions, recipe creativity assessment was addressed as a classification problem (Kotsiantis 2007).

Proposition 4 *There exists a continuous underlying dimension of creativity, and therefore, there are degrees of creativity, i.e., some products are more creative or less creative than others* (*Amabile* 1982; *Getzels and Jackson* 1962; *Guilford* 1959; *Nicholls* 1972; *Torrance and Goff* 1989).

Proposition 5 *Novelty is a sound estimation of creativity for elBulli's recipes (from MacKinnon's definition of creativity).*

Proposition 6 *Novelty of elBulli's recipes can be approached by their creation year. From MacKinnon's definition of creativity, we can safely make this assumption for the reason that more and more dishes and them being always different from one another prove the recipes' growing novelty every year* (*see Fig.* 2).

Proposition 7 *Written recipes can be limited to their list of ingredients and cooking techniques with insignificant loss of information with respect to the original recipe. It is acceptable that recipes can be reduced to their list of ingredients in experiments where the recipe is the subject of analysis* (*e.g., Ahn et al.* 2011; *Wen et al.* 2015). *The validity of this simplification is normally not questioned. In the present analysis, the list of preparation techniques is added to the*

[6] Programming language (https://www.python.org/).

[7] Natural language processing library (http://www.nltk.org/).

[8] Data analysis library (https://pandas.pydata.org/).

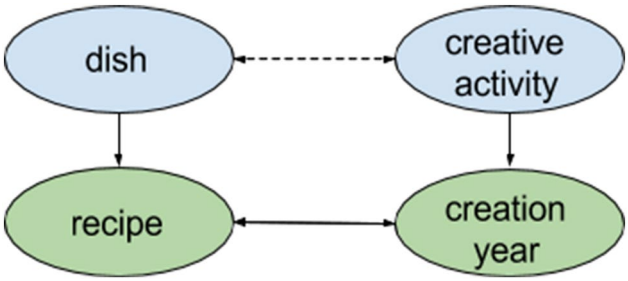
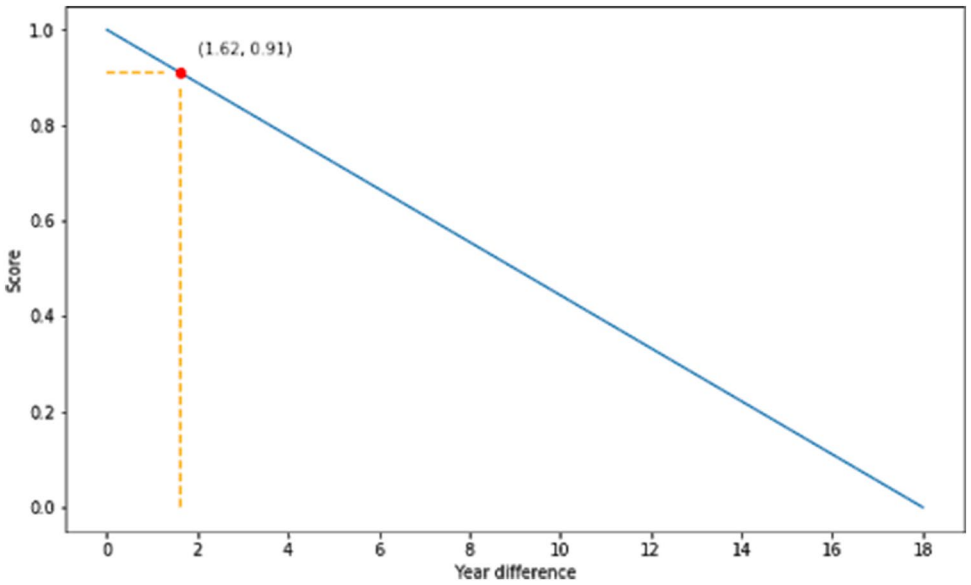


Fig. 3 Problem transformation

Fig. 4 Scoring function



list of ingredients, so the loss of information with regard to the original recipe is insignificant in this context.

Proposition 8 *By proposition 7, recipes can be bound by their list of ingredients and techniques, and in accordance with propositions 3, 5 and 6, their level of creativity can be assessed by estimating their creation year. Figure 3 illustrates the transformation of the original problem "dish/creative activity" into "recipe/creation year".*

Once the problem was defined, the classification model was built in the following way: for the 1214 recipes, the list of ingredients and techniques were set as features, and so was the creation year as the target of the classification model. We did not include the recipe's id and title in the set of features, as they do not provide information about the recipe's composition. Then we modeled a recipe as follows: let I be the list of the 2130 total unique ingredients, $I = \{i_1, i_2, \ldots, i_{2130}\}$, and T, the list of the 235 total unique techniques, $T = \{t_1, t_2, \ldots, t_{235}\}$; then a recipe can be defined as a vector of $2130 + 235$ binary values, where each of these values represents the presence or absence of every ingredient and technique in that specific recipe: $\text{recipe}_k = < i_{1k}, i_{2k}, \ldots, i_{2130k}, t_{1k}, t_{2k}, \ldots, t_{235k} >$, where k takes values from 1 to 1214. The resulting dataset has a size of 1214 observations by 2365 features. Therefore, although the approach to determine the case study was qualitative, the methodology is from now on quantitative.

To discover the patterns that associate the set of features to a creation year, we trained several classification models and calculated their score. We used Scikit-Learn[9] for these tasks. We avoided overfitting and ensured high data-independent performance by applying k-fold cross-validation ($k = 10$ in our experiment) with stratification (recommended in cases of imbalanced data like this, that is, some years has more recipes than others), and grid search for the best parameters of each classifier. The scoring function was customized for this particular problem. It calculates the difference between the true year and the predicted year and then it normalizes it to the range [0–1]. The maximum difference in the range [1987–2005] is 18, which corresponds to a score

Table 2 Classifiers and scores

	Score
K neighbors classifier	0.812068
Linear SVC	0.892552
MLP classifier	0.899725
Random Forest Classifier	0.908469
SVC	0.897182

[9] Machine learning library (http://scikit-learn.org/).

of 0. On the other end, when the minimum distance is 0 (true year = predicted year), the score is 1 (see Fig. 4). Table 2 shows the classifiers trained and their respective scores. The high scores obtained prove that posing the dependence between a recipe's features and its creation year as a classification problem was a correct decision. An average score of 0.91 means that the classifier predicts the correct year of a recipe with an error of ± 1.62 years (Fig. 4).

The search for the best predictor among different models obeys the *no free lunch* theorem. The theorem states that there is no one model that works best for every problem (Wolpert and Macready 1997), so no a priori assumptions about which one will perform best can be made (Wolpert 1996). From the tested classifiers (Table 2), the winner was the Random Forest Classifier.

5.3 Selected model

The Random Forest Classifier belongs to the family of ensemble methods, which combine the predictions of several base estimators/classifiers built with a given learning algorithm to improve generalizability and robustness over a single estimator/classifier. Random forests are a combination of decision trees although the former improve accuracy and correct the overfitting habit of the latter (Breiman 2001; Breiman et al. 1984).

A decision tree is a non-parametric supervised learning method that predicts the value of a target variable by learning decision rules inferred from the features. Battula and Satya Prasad (2015) introduce a complete literature review on the matter. These authors designed a machine learning method based on decision rules that outperforms classic decision tree algorithms. The method (similar-to-different, S2D) mimics the human learning process in which similar contents are iteratively studied first and different contents are left for later. The rationale behind S2D is that learning is a gradual process of accumulating knowledge, where learning similar cases first may make learning subsequent different cases easier so that the whole learning process is more reliable.

Our interest in Battula and Satya Prasad's paper (2015) lies in the commonalities between our studies. Like us, they based their model on decision rules. According to the authors, they are simple, widely applicable to real-time problems, highly efficient, and accurate. On the other hand, they built their model by applying tenfold cross-validation with stratification, and so did we (as mentioned above). These facts validate our own model and reinforce our decision to apply these same strategies.

The convenience of decision rules for our study is that their applications in human-oriented learning tasks may be fruitful, especially in cognitive ones (Battula and Satya Prasad 2015). Therefore, as cognitive learning tasks, creativity (Vidal 2009) and its assessment (Silvia et al. 2008) may be highly benefited from decision rules. Besides, they are human-interpretable, which is a requirement of our specific case study to identify what ingredients and techniques are the most relevant to predict the creation year.

The next section shows our key findings, resulting from the application of this classifier.

6 Results

Once the classifier was trained and tested, we ran several experiments that we describe below. The visualizations were generated with Matplotlib.[10]

6.1 Most informative features

elBulli kept some ingredients and techniques from season to season, but some others were discarded while new ones were incorporated into the catalogue, leading to a renewed menu with innovative preparations and recipes every season. Figure 5 shows the total number of unique ingredients and techniques by year, and how they affected the growth of recipes created. Although, as an overall trend, they all gradually raised over time, only the ingredient and the recipe curves follow a similar shape (in logarithmic scale). This result agrees with the divergent thinking principle that "quantity breeds quality" (Vidal 2009), that is, lots of ideas are required to have good ideas; or in this situation, the more different recipes are created in that season.

Table 3 shows the most informative features by ingredient and by technique. Informative features are those that let the classifier make better predictions—they are not necessarily related to the most frequently used ingredients or techniques. It is noteworthy that, with the exception of agar and glucose, the most informative ingredients and techniques are traditional and, therefore, far from what "modernist cuisine" (Myhrvold et al. 2011) is expected to be.

One of elBulli's hallmarks is making recipes as combinations of savory preparations (belonging to the savory world) or sweet preparations (belonging to the sweet world) or a mix of both. Figure 6 displays the average number of savory preparations and sweet preparations (and the sum of both) per recipe for each year. This information is useful to identify the central years, where savory and sweet preparations per recipe are balanced, in opposition to the years at both ends, where the savory world prevails over the sweet world. There are five features among the 20 most informative ingredients that are directly related to the two worlds: sugar, glucose, and isomalt in the sweet world; and common

[10] Plotting library (https://matplotlib.org/).

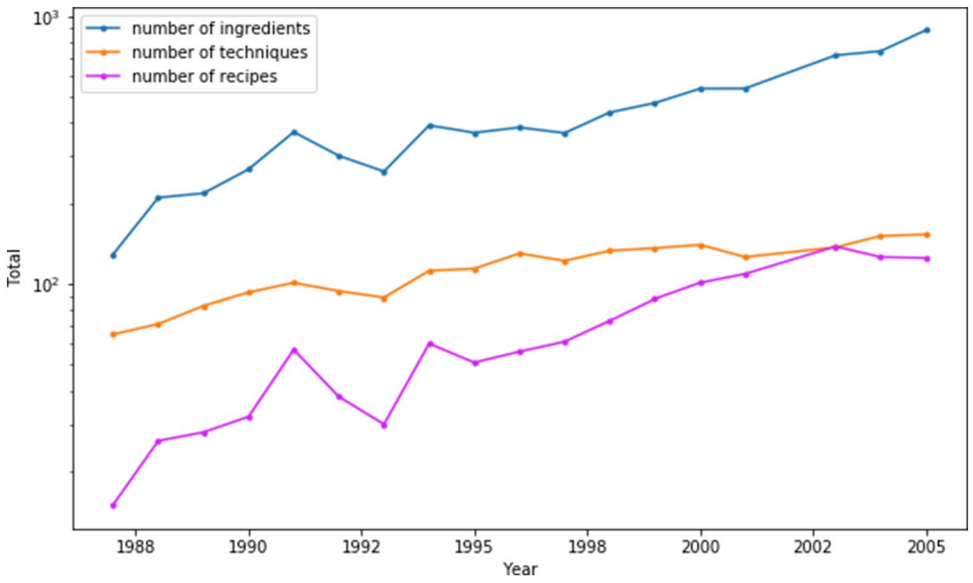


Fig. 5 Temporal evolution of the total number of ingredients, techniques, and recipes by year (logarithmic scale)

Table 3 Most informative features by category

#	Ingredients	Techniques
1	Agar	Crush
2	Water	Boil
3	Sugar	Mash
4	Salt	Bake
5	Olive oil	Oven
6	Jelly leaf	Colar (strain, filter)
7	Glucose	Pelar (peel)
8	Chervil	Mezclar (mix)

table salt and Maldon salt in the savory world. Figures 7 and 8 show their evolution over time.

Sugar has been steadily used throughout the whole period; even it raised significantly, along with glucose, in the central years. However, they both decreased while isomalt increased at the end of the period (Fig. 7). The increase of sweet ingredients in the central years is consistent with the increment of sweet preparations displayed in Fig. 6. These three ingredients define three periods clearly differentiated: 1987–1992, 1993–2001, and 2002–2005. On the contrary, salt has been gradually decreasing until 1992, when it

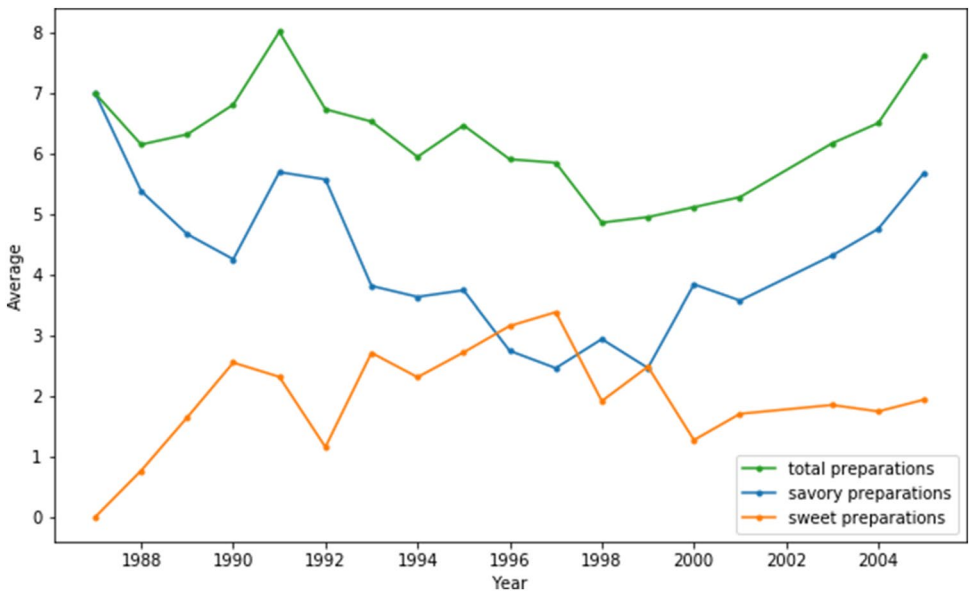


Fig. 6 Temporal evolution of the average number of savory (blue) and sweet (yellow) preparations per recipe by year (linear scale)

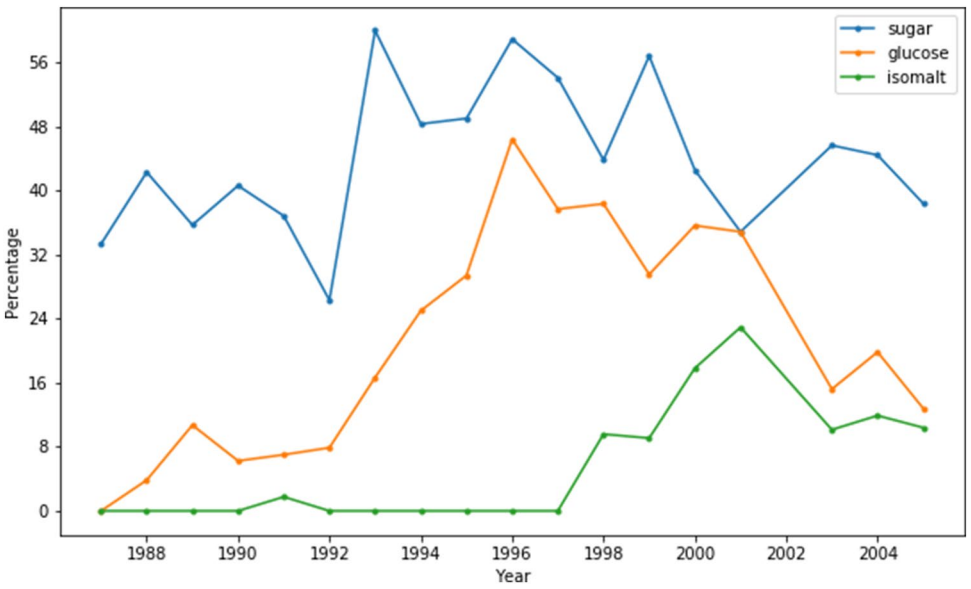


Fig. 7 Percentage of recipes that contain the most representative sweet ingredients by year

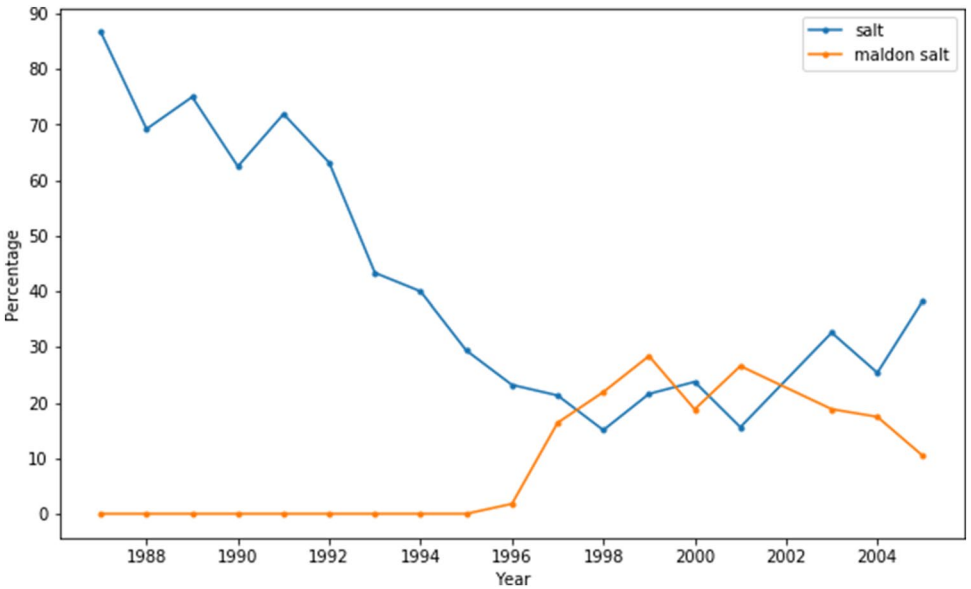


Fig. 8 Percentage of recipes that contain the most representative savory ingredients by year

plummeted to be present in less than 20% of the recipes in 1998. Conversely, the use of Maldon salt climbed since 1996 and coexisted with traditional salt for the second half of the period (Fig. 8). These two ingredients delimit three time intervals: 1987–1992, 1993–1996, and 1997–2005.

Figure 9 charts the use of the five most informative ingredients (excluding sugar and salt, already represented in previous images). We can observe the decline of traditional ingredients like olive oil and chervil, as well as the raise of a basic product such as water. Jelly leaf, like water, increased its presence for the last two-thirds of the period. Agar, however, was extensively used around 2000 and onwards. Figure 10 shows that olive oil was partially replaced by virgin olive oil and extra virgin olive oil.

The five most informative techniques are shown in Fig. 11. Boiling is the most enlightening feature in this category, as it jumped from being the most used technique in 1987 to being employed in only 30% of recipes in 2005. The usefulness of the rest of techniques for predicting the creation year is fuzzy except for the central period, from 1994 to 1997, when the top techniques are utilized in similar proportions (50–70% approximately), which is significant to identify this time frame. For the two intervals on both ends, techniques cannot explain the recipes' cooking styles on their own. Like in the case of the ingredients, it is noteworthy the fact that no modern cooking techniques, like spherification, lyophilization or the use of

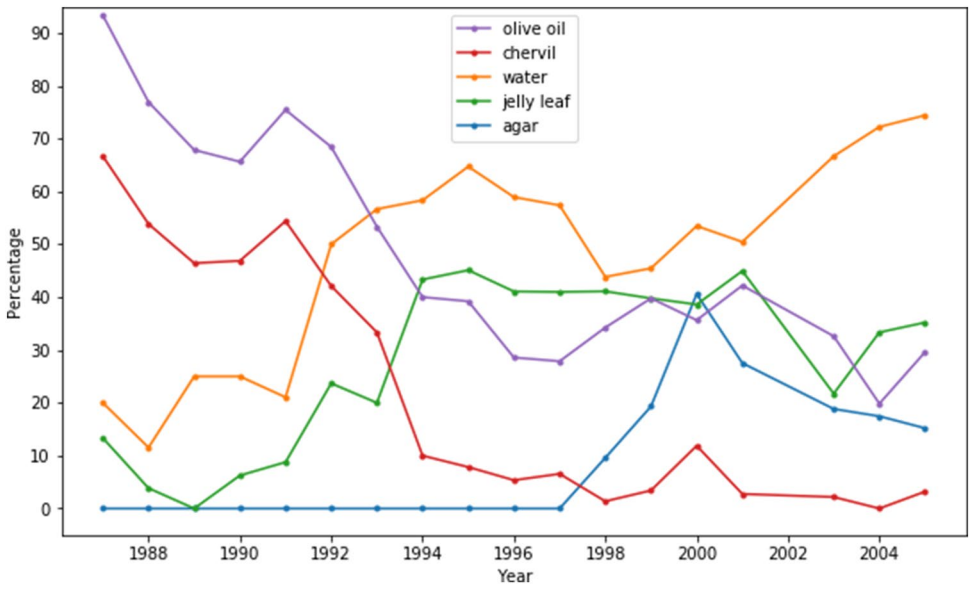


Fig. 9 Percentage of recipes that contain the most informative ingredients by year

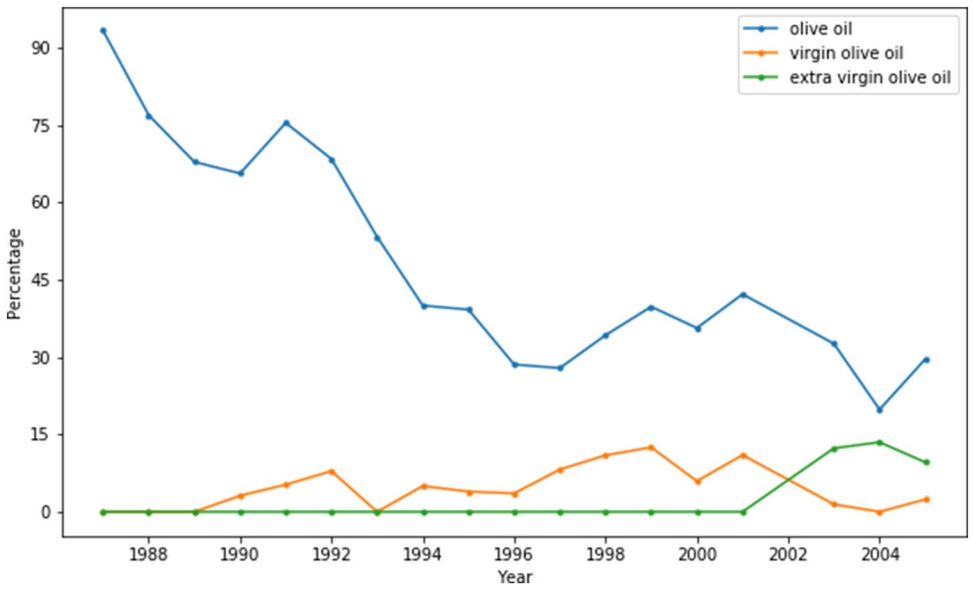


Fig. 10 Percentage of recipes that contain the different types of olive oil by year

liquid nitrogen, are among the 20 most relevant techniques for the period studied here (1987–2005).

The previous images show that the use of certain products in specific seasons and their replacement with new ones in the following seasons define elBulli's cooking style in each period. No single technique or ingredient, no matter how unique or modernist it is, weighs enough to create a new style by itself. That is, culinary creativity is not attached to a small group of ingredients and techniques, but to a complex combination of all of them. This complexity, partially represented in Fig. 1, was elBulli's hallmark. Adrià had warned us that his cooking style was not always linked to expensive ingredients or avant-garde techniques (typically related to high cuisine)—the quality of daily market products and the way they were cooked (using both traditional and modern techniques) were much more important factors for him. These results are consistent with Capdevila et al. (2015) research on Ferran Adrià and the creative process at elBulli—they affirmed that creativity is more related to new uses and combinations of existing ingredients and techniques rather than to new ingredients or innovative techniques—and with Ahn et al.'s (2011) work on recipes and food pairing—"the scientific analysis of any art, including the art of cooking, is unlikely to be capable of explaining every aspect of the artistic creativity involved."

6.2 Continuity of creativity

The scoring function defined for this problem (Fig. 4) was built upon our assumption that creativity evolves

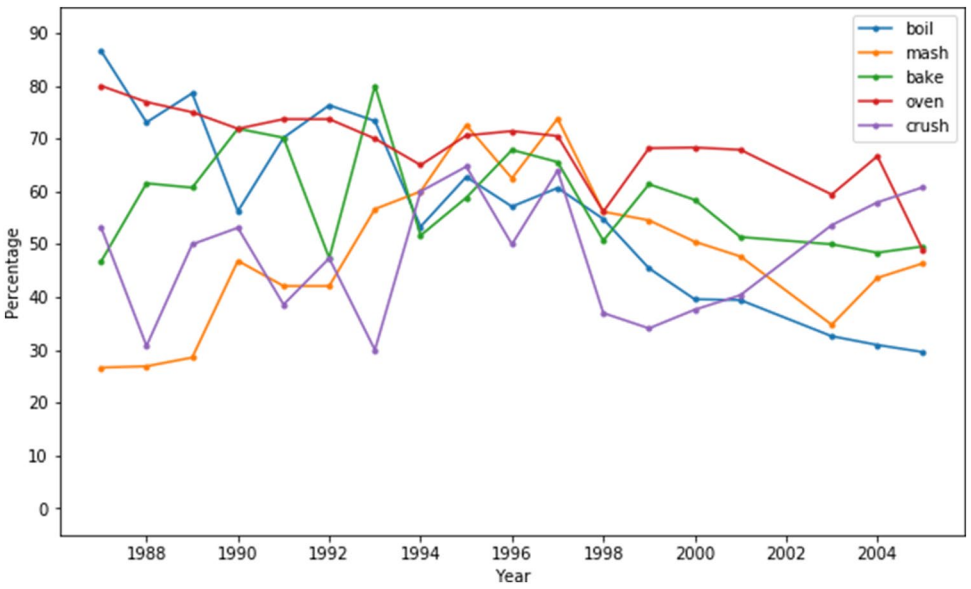


Fig. 11 Percentage of recipes that contain the most informative techniques by year

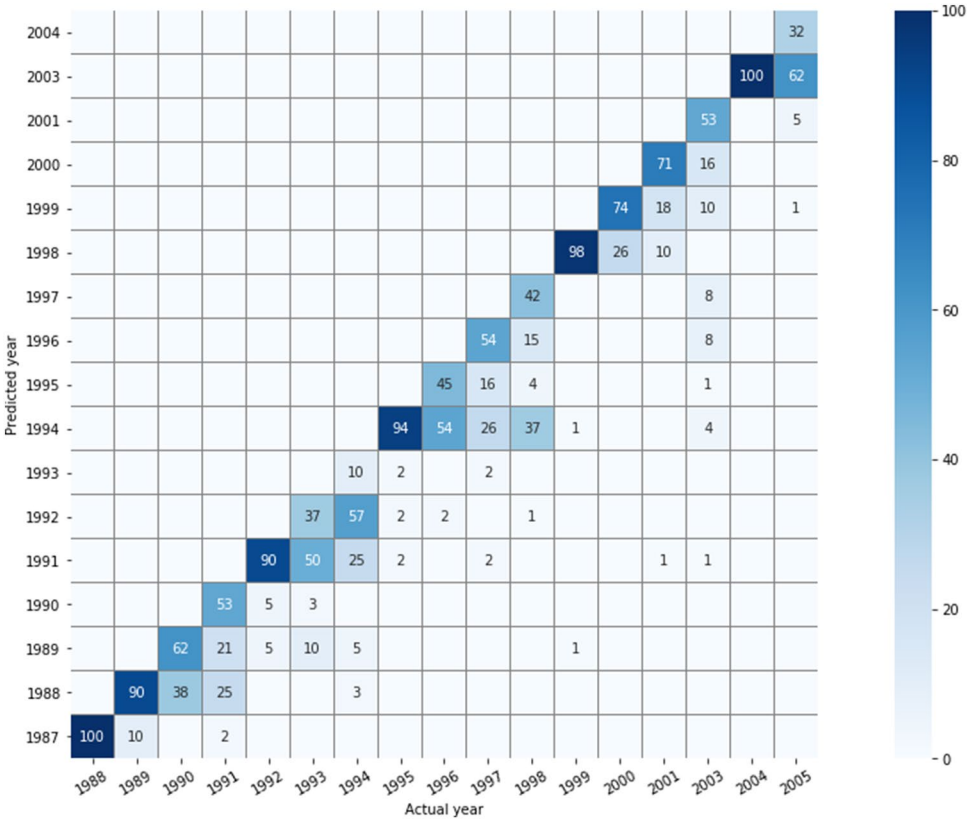


Fig. 12 Year prediction for unseen recipes

continuously over time rather than randomly (Proposition 6, Fig. 2), that is, the creative activity in a year is similar to the activity in years around. To test this hypothesis, we run the following experiment:

For every year, *Y*, in the range [1987–2005], repeat this process:

1. Train a Random Forest Classifier with the recipes created from 1987 to *Y*−*1*.
2. Predict the year of the recipes created in *Y*.

The question we aimed to answer is: how would the classifier perform when trying to predict the creation year of unseen recipes?

Figure 12 displays the new testing classifiers' performance, represented by a confusion matrix where the true creation years are in the *x*-axis and the predicted creation years are in the *y*-axis. For each tested year in the range (*x*-axis), the corresponding column uncovers the predicted classification of its recipes (in percentage) in the preceding years (*y*-axis). The higher values are in the antidiagonal of the matrix, that is, for every year, most of its recipes were classified in the immediate previous years. This is particularly evident in 1989, 1992, 1995, 1999, and 2004, where over 90% of its recipes were classified as belonging to the prior year. This means that the ingredients and techniques used in the recipes are very similar from one season to the next one.

The image also reveals five reasonably well-defined triangles just below the antidiagonal of the matrix. These are formed by the actual years (1) [1989, 1990, 1991], (2) [1992, 1993, 1994], (3) [1995, 1996, 1997, 1998], (4) [1999, 2000, 2001, 2003], and (5) [2004, 2005]. These triangles suggest the existence of clusters of years with blurrier borders and whose recipes are alike. The years 1989, 1992, 1995, 1999, and 2004 mark the beginning of each cluster that, in any case, is the continuation of the previous one. This result is especially relevant because in classification, unlike regression, the target feature (in this case, the creation year) is not a variable that takes values from a continuous range. On the contrary, years 1987–2005, although interpretably continuous for a human mind (and represented as such in the previous figures from Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12), are actually disconnected labels from one another and do not have any kind of sort order; and yet the classifier was able to find this intrinsic order relation.

The implication of this finding is that creativity is not a ground-breaking activity, but an evolving process based on previous activity. This vision of creativity agrees with most theorists in the field. At the level of persons, the creative individual must have extensive domain knowledge to create something new (Csíkszentmihályi 1997; Sternberg 1998). At the product level, this result reinforces previous conclusions from other authors in the field. Glăveanu (2014) affirmed that nothing is truly original in the absolute sense of the word since creative products do not emerge "out of thin air, but out of the (re)combination of whatever exists." Cropley (2009) said that products need to be novel "and yet routine." This affirmation is related to the usefulness of the product (the other key pillar of creativity). Ciborra (2009) tied the creation of new products to a gradual extension of known tools and techniques, everyday experience, local knowledge, and routine behavior. This is what he names *bricolage*, on-going fluctuations in local practices and progressive breakthroughs that lead to innovations. Veryzer (1998) found that although novelty was needed, customers preferred products that had some newness, but were not radically different from existing product lines. Products cannot be too innovative nor ahead of the market (Gruenwald 2001). The reason is that people need to understand the new product to accept it. To achieve so, creativity has to follow the established rules (Frand 1989). Our result is therefore consistent with Frand and with Capdevila et al. (2015), who stated that creativity at elBulli is related to experimenting with existing, commonly accepted rules. It likely supports research (Suárez and Sancho-Caparrini 2013) that highlights the design and implementation of a method of sustainable creativity as the main feature of elBulli's creative enterprise.

The idea of creativity as a continuous process has important implications in product development. An unjustified deviation from the established rules involves only pseudo-creativity (Cattell and Butcher 1968), while novelty that is impossible to put into practice involves only quasi-creativity (Heinelt 1984). Cropley and Cropley (2005) emphasized that both relevance and effectiveness along with novelty are a must for products; but they must also be understandable, usable, and acceptable to other people, especially in practical areas such as business (Cropley 2009). Christensen (1997) gave examples of novel products that did not fit into the existing framework and customers rejected them. elBulli institutionalized this practice in its catalogues under the categories of dishes "that could have been, but did not." Cooley (2007) called it "paths not taken". He defended that technological innovations must be human-centered and socially useful for the benefit of both producers and consumers (1982). Therefore, as stated in the multiple definitions of product creativity, creative products require both novelty and usefulness.

7 Conclusions and future work

Ferran Adrià and his team developed a method to achieve the objective of a truly creative form of culinary art that was translated into a wider variety of dishes, as well as more innovative, both aesthetically and culturally. Adrià's commitment to creativity led the chef to seek innovation outside the field of gastronomy and embrace multidisciplinarity. He brilliantly bridged science, philosophy, art, and cuisine to bring creativity, innovation, and value in elBulli like no other restaurant in the world had done up to that moment. Its seasonal operation, serving dinners only, and the opening of a workshop/lab to do research in the off-season, are examples of decisions that obeyed a joint strategy for adaptation, with an aim at devoting more resources—mainly time and space—to gastronomic research, and an effort to maintain the competitive advantage over other restaurants.

To limit the scope of our analysis and make answering the research questions feasible, we included specific propositions that came from the literature and from our own empirical data. Our propositions resulted in the assumption that elBulli's recipes can be bound by their list of ingredients and techniques; and their level of creativity can be assessed by estimating their creation year. We gathered elBulli's recipes from the period 1987–2005 for a total of 1214 recipes, 2130 unique ingredients, and 235 different cooking techniques. Then we trained a Random Forest Classifier that inferred the patterns of interdependence of the creation year on ingredients and techniques (Jimenez-Mavillard and Suarez 2020). Upon analysis completion, we were in a position to answer the research questions.

RQ #1: How can creativity in the product be characterized? What are these attributes in elBulli's culinary creations? By taking the written recipe as the culinary product, we characterized every of the 1214 recipes as a vector of 2365 components, from which 2130 are ingredients and 235 are cooking techniques. The presence or absence of each of the ingredients or techniques produces differences in the level of creativity (ranging from 0 to 1) in every recipe. This characterization is consistent with the product-based approach (Horn and Salvendy 2006). The high scores obtained by the Random Forest Classifier (0.91/1 with an error of $\pm$ 1.62/18) prove that posing recipe creativity assessment as a classification problem, with the election of ingredients and techniques as features and creation year as the target, was the right decision for this problem.

RQ #2: From the identified attributes that characterize elBulli's products, are there any subset and/or specific quantities for them that are exclusive of creativity? Can product creativity at elBulli be unequivocally defined by a particular set of attributes and a range of values? The answer is no. This result agrees with the common opinion that no single ability or trait is the key to creativity (Barbot et al. 2011) and that the scientific analysis of cooking is unlikely to be capable of explaining every aspect of the artistic creativity involved (Ahn et al. 2011); we could not prove the opposite. The classifier found that certain ingredients and techniques were the most informative for it to make better predictions, but most of them are very common and traditional and, therefore, far from what high cuisine is expected to be. That is, creativity is not attached to a small group of ingredients and techniques, but to a complex combination (Capdevila et al. 2015) of all of them, regardless of their market price or their avant-garde.

RQ #3: Is the creative product a truly original outcome of the creative person and the creative process? How radically novel can new products be? Do elBulli's new creations resemble its preceding creations, and if so, to what extent? Creativity is not a ground-breaking activity, but an evolving process based on previous activity. Creative products do not emerge from nowhere, but the recombination of whatever exists (Glăveanu 2014). The reuse and recombination of ingredients and techniques suggests that the creative individual must have an extensive domain knowledge to create something new (Csíkszentmihályi 1999; Sternberg 1998). New products must be novel and yet routine (Cropley 2009) in a way that is understandable and, therefore, useful for the intended target.

This paper attempts to make three contributions to the field of culinary creativity. The first is an accurate AI-based method for assessing product creativity that can help professionals of the gastronomy industry and creativity practitioners create new culinary products, identify their weaknesses and strengths, and maintain a sustainable competitive advantage. This major outcome was applied to rate the adoption of elBulli's innovation by the users of two popular recipe websites: Allrecipes[11] and Epicurious[12] (Jimenez-Mavillard and Suarez 2020).

The second contribution is a better understanding of the concept of creativity and assessment methods by two means: (a) an exhaustive compilation of creativity definitions and assessment methods that reconciles the many theoretical frameworks that scholars and researchers contributed to the field, and (b) by interpreting the results of the experiment to answer the research questions.

The third contribution is a methodological framework that can be applied to other artistic fields to explain other cultural phenomena analogous to elBulli's case. In particular, the fields of art and fashion are strong candidates to be studied in the same way. The communion of these three areas is evident in events such as Gastrofestival,[13] held annually in Madrid (Spain), where tribute to gastronomy is paid not only from a culinary standpoint, but also from other perspectives such as art, literature, photography, cinema, or fashion. Key steps of this methodology would be the identification of an exemplary case study and data collection that would enable the analysis. The results in the areas of art and fashion could help to explain, for example, how new trends in fashion shows influence the genre of department stores and, therefore, our closets; or how specific avant-garde artistic manifestations are present in exhibitions and art galleries in the world.

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