



# Empirical exploration of the 4P theory of creativity using virtual reality

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## ABSTRACT

In the 4P theory of creativity, Rhodes in 1961 emphasises the importance of different components in human creativity, which arises from the dynamic interplay of four key components: *Person*, *Process*, *Product*, and *Press*. Following previous studies that focused on relations among the 4P components, we conducted an exploratory empirical study with a sample of 60 participants using virtual reality. In our study we investigated: *Person* through self-report questionnaires on participants' personality and creativity traits; *Process* through the registrations of users' interactions during a VR task in which they create artworks; *Product* through a semi-automated ontological analysis of the artworks' features; *Press* by altering the virtual environment with contextual auditory stimuli.

Our research contributes to the study of creativity, using Virtual Reality as a platform for an empirical investigation of the relations between the 4P components of creativity. Our findings suggest an intricate network of components, with significant correlations for 5 out of 6 relations. Our findings are in line with previous research about the relation between *Person* and *Process*, between *Person* and *Press*, and between *Process* and *Product*, and show novel insights about the relation between *Person* and *Product* and between *Press* and *Process*.

We have applied our novel method to the original 4P foundational domains, demonstrating its utility to lay a research ground to formally (via ontological distinctions) and empirically (based on explicit and implicit measures) compare creativity theories that extend 4P components, possibly addressing cognitive abilities, expertise and impact levels, error functionalization, creativity dynamics, etc.

## 1. Introduction

According to the 4P theory outlined by Rhodes in 1961 (Rhodes, 1961), creativity cannot be reduced to its products, encompassing instead multiple aspects, which are schematised in 4 components: *Person*, *Process*, *Product*, *Press*. These components can be summarized as follows (Lucifora et al., 2023):

- *Person* includes the personality traits of creative people. Rhodes defined *Person* as the personal traits of a creative person. It indicates habits, behaviours, and temperament (Gong et al., 2022). Feist (1998, 2010) states that subjective variables related to genetic, cognitive, and social traits can influence the creative personality of humans
- *Process* includes the actions that creative people do to build a creative product. It is about the specific actions people do to build a creative artwork, which are linked to their thinking and motivation (Gong et al., 2022). Wallas (1926) intends *Process* as based on specific

phases that can be overlaid during the process. These phases include preparation, incubation, insight, and verification.

- *Product* includes creative ideas/products. It is about creative ideas or artworks (Rhodes, 1961) that may feature novelty, utility, and surprise (Simonton, 2013, 2017, 2018). These characteristics can be combined, based on a multiplicative integration of the probability of a creative idea ( $p$ ), its final utility ( $u$ ), and the previous knowledge about utility ( $v$ ) (Lucifora et al., 2023).
- *Press* includes the environment of creativity (fruition, critique, cultural and situated influences, etc.). It is the social and/or physical environment that can influence a creative person (Gong et al., 2022).

Even if other studies investigated the 4P components (see Sect. 2), showing significant relationships among them, the current literature lacks a more integrative approach to the relations among all the components and their rationale. To fill this gap, our research innovatively explores the four components in a Virtual Reality (VR) scenario, designed to facilitate the study of human creativity thanks to VR key

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features: immersion, interaction and imagination (Burdea & Coiffet, 2003; Yang et al., 2018).

Our research, based on a rigorous conceptual framework of the creative domain, is a multi-method study that combines psychometric tests, behavioural experiments, and environmental assessments using VR, to examine all 4Ps components simultaneously, and to disentangle their relations. Our findings reveal significant relations that support a unified vision of the 4Ps theory, offering a solid and relevant contribution to creativity research.

The 4P theory of Rhodes (1961) is still a good theoretical foundation and has the advantage of straightforwardly identifying and defining four crucial factors accounting for human creativity. Our proposal is to formally and empirically characterize the components of creativity, also enabling the characterization of future extensions and evaluation, as the 8P Theoretical Framework recently proposed by Sternberg and Karami (2022).

We developed a paradigm for the parallel analysis of a limited number of factors composing human creativity within a same experimental setting, quantitatively assessing the relations among the four components. The actual interactions that can be expected based on their significant relations can then be studied as formal variations of the paradigm.

## 2. Literature review on 4P theory

Previous studies explored relations among the 4P components. For example, the study of Batey and Furnham (2006) investigated the relation between *Person* and *Process*. Using a sample of 158 university students, they evaluated relations between personality traits, intelligence (fluid and IQ) and the ideational behaviour. Their findings show that the ideational behaviour is positively associated with openness to experience and negatively with agreeableness, in this sense personality traits, rather than intelligence (IQ and fluid) constitute a predictor of creativity. Similarly, Puccio and Grivas (2009) scrutinized the relationship between personal traits and the phases of a creative process, such as ideation, planification and implementation. Their results, obtained on a sample of 137 participants, have shown that calm and analytic people are more interested in the clarification of a problem, while people that prefer generation of innovative ideas are more available to change.

From a distinct perspective, Kaufman et al. (2016) investigated the relation between *Product* and *Process*, considering the creative outcome and the self-evaluation of creative performance. Using a sample of 247 elementary school students, they examined three domains of creativity (i.e. visual, verbal, and scientific domain) asking children to complete different tasks and to judge their creativity in each of them on a 5-point Likert Scale. Results show a positive relation between students' self-evaluation of creativity and their creative outcome. Similarly, Amabile (1996) focused on the relation between *Process* and *Product*, highlighting that relevant skills and task motivations have an influence on the creative outcome.

Due to its multifaceted nature, the *Press* factor is more complex to explore. We report below the scientific works that examined its correlation with *Person*, *Product*, and *Process*. Focusing on the relation between *Press* and *Person*, Rubenson and Runco (1992) demonstrated that psycho-economic factors can influence the creative ability of people. Their results were discussed considering a theoretical model based on the concept of human capital and related to a creative potential present in each person, which depends on intrinsic and extrinsic factors, like education. Similarly, the study of Sternberg and Lubart (1991) showed that also the environment strongly influences personal ideas, corroborating the hypothesis that creativity is not inborn but instead depends on social investment. Concerning the relationship between *Press* and *Product*, Csikszentmihalyi (1997) discusses the importance of the environment in determining what can be considered a creative outcome. In this sense, a creative product is not creative by itself, but it depends on the

specific domain in which it is included (e.g., music, visual art, etc.). Finally, about the relation between *Press* and *Process*, the study of Dul et al. (2011) demonstrated that physical characteristics of objects in an interior design, such as the size, shape, and organisation, can influence the creative performance of the users.

## 3. Creativity: An ontological analysis

With the aim of drawing inferences across different theories, and designing experiments based on shared definitions of aspects from creativity phenomena, in previous work (Lucifora et al., 2023) we designed a creativity ontology derived from psychological theories and neuroscientific findings. Ontologies are data models axiomatized in some fragment of first-order logic, OWL2 (the Web Ontology Language, Grau et al., 2008). Ontology axioms capture the intended meaning of a domain or a theory, enabling automated reasoning and querying of a dataset shaped according to the ontology. Our ontology follows best practices in ontology design (Gangemi & Presutti, 2009) to integrate multiple creativity theories and fostering their comparison and evaluation with respect to cognitive and real-world data.

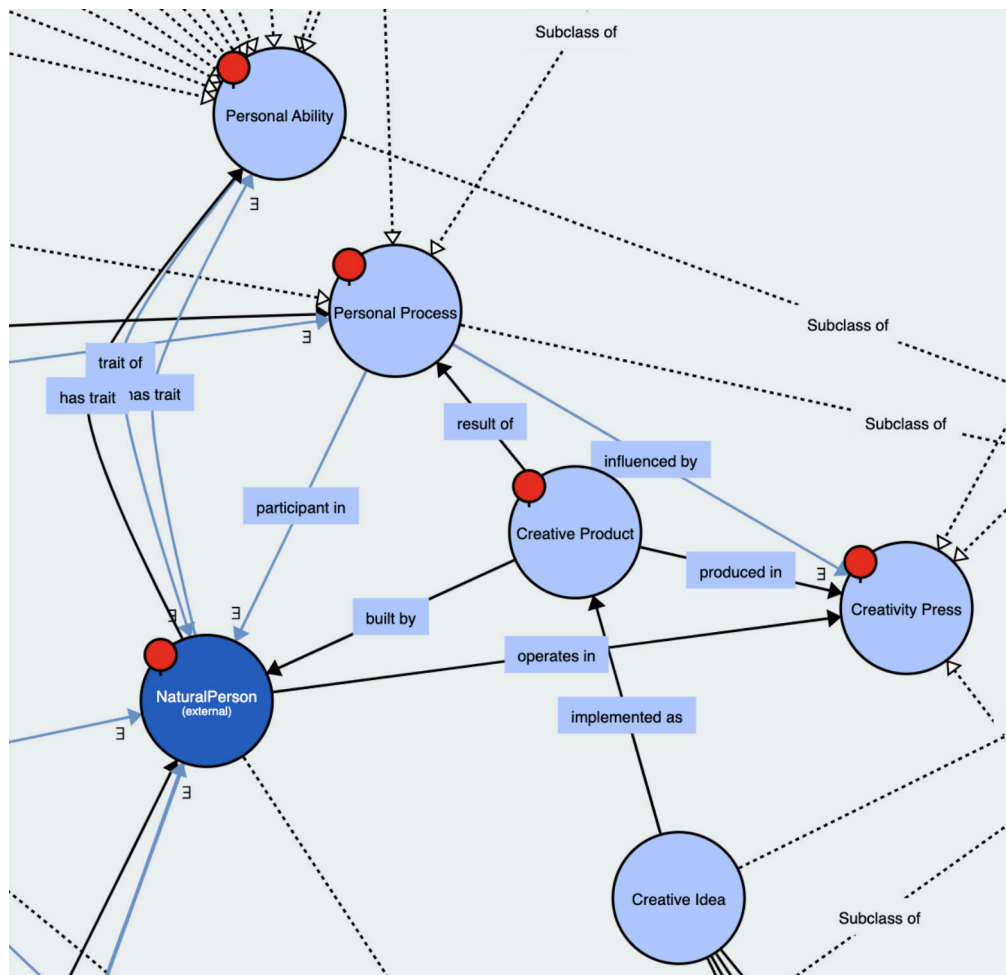
Our creativity ontology moves from the 4P theory of Rhodes (1961), firstly representing the core 4P model as a set of classes (denoting the set of objects featured by the 4P components), and their relations (denoting the set of associations between each pair of classes), as represented in first-order axioms A1–A2 (see Fig. 1). A1 introduces a 4P relation pattern (i.e., an axiom schema) assuming that for each creative situation there is at least one instance of the types of things that are considered in the four components (persons and their personal traits/competences for *Person*; situations for *Process*; entities whatsoever for *Product*; situations for *Press*). A2 asserts that for each pair of those instances, a specific relation holds between them, e.g., that a specific person is influenced by a (contextual) situation, as formalized below.

$$4P(p, pe, pr, pd, ps) \rightarrow \exists (p, pe, pr, pd, ps) (\text{NaturalPerson}(p) \wedge \text{PersonalAbility}(pe) \wedge \text{hasTrait}(p, pe) \wedge \text{Situation}(pr) \wedge \text{Entity}(pd) \wedge \text{Situation}(ps)) \quad \text{A1}$$

$$4P(p, pe, pr, pd, ps) \rightarrow \exists (p, pe, pr, pd, ps) (\text{participatesin}(p, pr) \wedge \text{influencedBy}(pr, ps) \wedge \text{builtBY}(pd, p) \wedge \text{resultOf}(pd, pr) \wedge \text{operatesin}(person, ps)) \quad \text{A2}$$

The types and relations used are axiomatized in specific “ontology design patterns” (Gangemi & Presutti, 2009) that are reused to make similar distinctions across domains and across use cases, inducing “semantic interoperability” across them. These axioms ground the experimental setting of our study, as well as the space of correlations emerging from the exploratory study, to agree on a sharable interpretation of Rhodes' theory. The diagram of axioms A1 and A2 is shown in Fig. 1.

Once the minimal intended semantics of the 4Ps was established, we added related creativity theories with the goal of clarifying and integrate them. For this purpose, concerning the differences between personal and social creativity, we referred to Simonton's theory (2018): in that theory, “personal creativity” (*creativity*) is linked to people personal abilities (see also Guilford, 1950; Smith et al., 1995; Wallas, 1926); while “social creativity” (*Creativity*) is linked to the context in which people are involved (see also Amabile, 1996; Corazza, 2019; Csikszentmihalyi, 1997). To deepen the analysis of the *Person* component, we referred to the theories of both Sternberg (1988a, 1988b) and Guilford (1950), including the class of “personal abilities” i.e., fluid intelligence, associative processes, and divergent thinking. Finally, relying on the Default Mode Network (Raichle et al., 2001) and the Seeking System (Panksepp & Biven, 2012; Wright & Panksepp, 2012) the class of “personal abilities” was linked to “neural patterns”, consistently with experimental findings from neuroscientific literature on creativity (Bhattacharya &



**Fig. 1.** An excerpt of our ontology (nodes represent classes, arcs represent relations), highlighting the 4P components through their main classes (NaturalPerson, PersonalAbility, PersonalProcess (Situation), CreativePress (Situation), CreativeProduct and their relations). This figure represents a diagram of A1 and A2 axioms as they would be represented in a logical graph-based language (OWL in this case, cf. Motik et al., 2008).

Petsche, 2005; Chryssikou et al., 2020; Kenett et al., 2020).

Since the ontology makes it explicit the relations between concepts and relations from different theories, we can compare what different studies are experimenting with, and their results. For example, from within the *traitOf / participatesIn* relation path between PersonalProcess and CreativeProduct, the results from Kaufman et al. (2016) can be modelled as correlations between some creative outcome (Product component) and self-evaluations of creative performances (situations from the Process component, as reported by subjects), while Amabile (1996) results can be modelled as correlations between personal skills and motivations (which are different from generic reported situations as in Kaufman et al., 2016), and the creative outcome itself.

#### 4. Materials and methods

We used the ontology to model our own experimental setting: we evaluated possible relations among: *Person*, based on the personal background of the users in term of personality and creative traits; *Process*, based on the creative performance of the users using a VR environment in which they can interact with 3D objects to create a virtual artwork; *Product*, using ontological analysis to evaluate the features of virtual artworks; *Press*, changing the virtual environment by using auditory/emotional stimuli, based on the pivotal role that emotions have in creativity (Amabile et al., 2005).

#### 4.1. Participants

Based on previous studies about VR and creativity (Fleury et al., 2021; Houzangbe et al., 2022; Obeid & Demirkan, 2023; Yang et al., 2018) we tested a total sample of  $N = 60$  university students composed by 23 males and 37 females with a mean age of 21,45 SD 3,53. We divided our total sample in three groups of 20 participants to address the Press aspect with an auditory stimulation related to a different emotional arousal (positive, negative and neutral). The first group (positive stimulation) is composed of 7 males and 13 females with an average age of 21 SD 3.44. The second group (negative stimulation) is composed of 6 males and 14 females with an average age of 22 SD 4.96. The third group (neutral stimulation) is composed of 10 males and 10 females with an average age of 21 SD 1.00. No gratuity was given to the participants. All the participants obtained informed consent. The local ethics committee of the University of Bologna (protocol number 0152607) approved the study.

#### 4.2. Measures

We employed multiple metrics to assess the 4P component features (see Table 1 for a summary):

For the *Person* component, we recorded the personal characteristics of the users, using two self-report questionnaires, i.e., K-DOCS (Kaufman, 2012) and Big-Five (John & Srivastava, 1999). Furthermore, the Italian version of the Remote Association Test (RAT) and the Rebus

**Table 1**

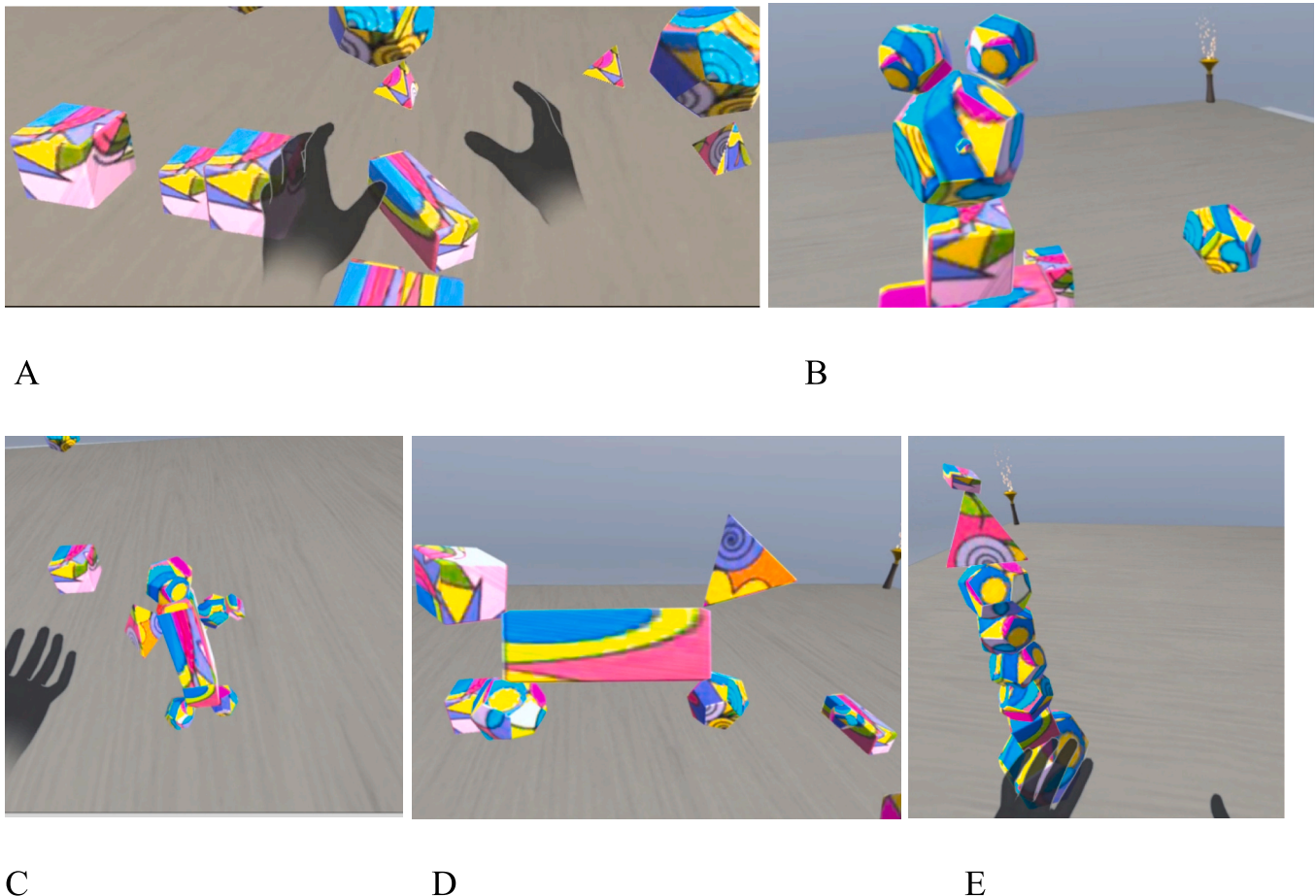
The ontological features of the artworks considered in our analysis. Each artwork is categorized in all dimensions.

Ontological features of the artwork subject	Description
Agency	The subject is/is not agentive (e.g. Child vs Snowman)
Functionality	The subject is/is not functional (e.g. Hammer vs Abstract Composition)
Biological	The subject is/is not biological (e.g. Koala vs Pinocchio)
Container	The subject is/is not a container of something else (e.g. Train vs Snack)
Scattered	The subject is/is not scattered (e.g. Solar System vs Hive)
Features	The subject is/is not represented with specific details (e.g. Man with hat vs Human)
Place	The subject is/is not a physical place (e.g. House vs Chandelier)
Concrete	The subject is/is not perceptual (e.g. Tree vs House on clouds)
Iconic	The subject is/is not iconic (e.g. Exclamation points vs City)
Fictional	The subject is/is not imaginary (e.g. Mickey Mouse vs Cat)
Autonomous	The subject is/is not autonomous (e.g. Pregnant Woman vs Lamp)

Puzzle test (Salvi et al., 2016) were administered before and after the VR experience.

- Kaufman Domains of Creativity Scale K-DOCS (Kaufman, 2012) is composed of 50 items on a 5-point Likert scale related to the study of creativity. This test assesses several types of creativity: *Self-Everyday Creativity, Scholarly Creativity Performance Creativity, Mechanical/Scientific Creativity and Artistic Creativity.*
- BIG-Five Inventory (John & Srivastava, 1999) is composed of 44 items on a 5-point Likert scale related to the study of different personality types: *Extraversion, Agreeableness, Conscientiousness, Neuroticism and Openness.*
- RAT test (Salvi et al., 2016) is divided into 4 categories, that are: Remote Association, Same domain, Additional letter, Idiomatic expression. We selected a total of 12 stimuli, administered 6 pre-VR and 6 post-VR counterbalanced. For each category we selected 4 tasks (2 pre-VR and 2 post-VR) related to the degree of difficulty that is “easy” and “hard” based on the percentage of error validated by Salvi et al. (2016).
- Rebus Puzzle test (Salvi et al., 2016) is based on 20 categories that are divided into 9 tasks, that are: Verbal interpretation, Spatial relationship, Mixed word and image, Mixed number, word and symbol, Fragmentation, Repetition, Word into Word, Anagram, Negation. We selected a total of 24 rebus, that were administered 12 pre-VR and 12 post-VR counterbalanced.

For the *Process* component, we calculated the number of interactions (i.e., the frequency of the user contact with 3D virtual objects) within the virtual world, using a timeline segmented into four steps. Based on the



**Fig. 2.** Our virtual environment, in which participants can interact with multicolour 3D objects using their personal hands (A) with the aim to build a creative artifact, e.g. “mickey mouse” (B), child (C), cat (D), tower (E).

study of [Graessler and Taplick \(2019\)](#), a creative process consists of separate phases, from the identification of a task to the assessment of a generated idea. We analysed the total time dividing it into four specific phases, starting after an initial period (time 0) where no interactions were recorded.

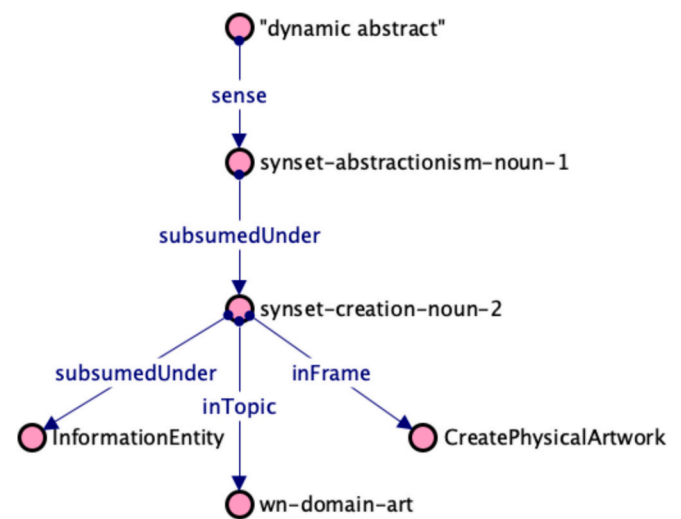
For the *Product* component, we focused on the final creative artwork created by our participants (see [Fig. 2](#)).

After creating the artworks, we asked participants “what is your artwork?” and we recorded their response (the intended type) and captured images of their work. These data were used to create a dataset intended for ontological analysis. Considering that no extensive quantitative measures are available about the product (for example, novelty and surprise should be assessed against personal knowledge and extensive public knowledge about a specific style or technique, which are not available in general), our analysis focused on both the ontological features of the subject of each artwork (e.g., being agentive, functional, biological, iconic, etc.) and the ontological features associated with the artwork as an information entity (e.g., the realism and the topological connection of the constituent parts of the artwork). To support feature detection, we firstly used automated methods, including the UKB tool ([Agirre & Soroa, 2009](#)) for word sense disambiguation against WordNet ([Fellbaum, 1998](#)), logical alignment to the DOLCE foundational ontology ([Gangemi et al., 2003](#)), frame detection with the FRED formal semantic parser ([Gangemi et al., 2017](#)), and topic detection. For example, the *dynamic abstract* virtual artwork is automatically disambiguated to the WordNet synset *abstractionism* using the UKB tool. The WordNet synset is on its turn formally represented as the class *synset-abstractionism-noun-1* in the knowledge graph<sup>1</sup> representation of WordNet 3.0. Since the WordNet 3.0 knowledge graph is included in Framester ([Gangemi et al., 2016](#)), a large factual-linguistic network that logically aligns many linguistic knowledge graphs, *synset-abstractionism-noun-1* results to be a subclass of the DOLCE foundational ontology ([Borgo et al., 2022](#)) *InformationEntity* class, through its top WordNet hypernym *synset-creation-noun-2*. Since Framester also includes the alignment ([De Giorgis et al., 2022](#)) of WordNet 3.0 to FrameNet ([Baker et al., 1998](#)), another linguistic resource that categorises the lexicon in terms of situational frames, we have detected the frame *CreatePhysicalArtwork*. Navigating the FrameNet taxonomy, we also know that the top FrameNet class for *CreatePhysicalArtwork* is *Event*. Finally, Framester contains further alignments of WordNet to ontologies of topics (in the example, it is *wn-domain.art*), emotions, sentiment, etc. (see [Fig. 3](#)).

Based on automated sense disambiguation and categorial analysis, we have selected ontological features that are associated with each artwork's subject, i.e., whether the subject (e.g., *beehive*) is *agentive*, *functional*, *biological*, *a container*, *scattered*, *evidencing parts or features*, *a heap of substance*, *a place*, *an entity having no space-time characteristics*, *concrete* (in a common sense, perceptual sense), *iconic*, *fictional*, *autonomous*, see [Table 1](#).

Finally, a manual evaluation has been performed to detect the ontological features that are associated with the artwork as an information entity, i.e., whether the artwork drawing features *realism* (naïve similarity between the drawing and the prototypical subject), and topological *connectivity* between the parts of the drawing.

For the *Press* component, we introduced in the virtual environment auditory stimuli, that is Bach's “Suite n.4” in both a positive and a negative version, as used by [Koelsch et al. \(2013\)](#). This manipulation aims to evoke emotions, which play a crucial role in creativity ([Amabile et al., 2005](#)). In the negative version, the amplitude of the sound was modified to evoke negative emotions to the users ([Koelsch et al., 2013](#)). The auditory stimulus was first presented 30 s after the onset and then



**Fig. 3.** Result of automated disambiguation of an artwork title within the lexical knowledge graph Framester. This enables the automated categorisation of an artwork with ontological features.

repeated 8 times at 30-s intervals - each auditory stimulus lasted 10 s. In the neutral condition, no auditory stimuli were presented to the users. We did an emotional check after the VR experience, asking participants to explain their feeling based on the Ekman's model of emotions (*happiness, sadness, surprise, disgust, fear, anger*).

For the sake of clarity, we summarize the way we approached this exploratory study, as well as the relations among the four components and the kind of output in [Table 2](#).

#### 4.3. Procedure

In our study we recorded demographic variables such as age, gender, occupation and asked the user to complete the self-report questionnaires about creativity (K-DOCS) and personality traits (Big-Five), administered in a random way. Then, to evaluate the divergent thinking of our participants we administered RAT and Rebus Puzzle Test ([Salvi et al., 2016](#)) before and after the VR experience.

Within the virtual environment, the user was asked to use the 3D object to build a creative artifact, using a total time of 5 min (as in a previous study, see [Yang et al., 2018](#)). We provided participants with general instructions about the task to avoid limiting or conditioning their creativity: to provide examples can alter the subjects' creative performance ([Marsh et al., 1996](#); [Smith et al., 1993](#); [Ward, 1994](#)).

Due to possible unwanted side effects (e.g., motion sickness), we minimized the number of artifacts, and the time to produce them. After the experiment, the total timing was segmented into four steps ([Chart 1](#)):

- Time 0: The initial 10 s in which there is no recording of interactions. This period serves as an orientation phase for users, allowing them to familiarise with the VR environment.
- Time 1: Spanning 80 s, it is the incipit phase in which we capture the initial interactions and observations of the users.
- Time 2: Extending over 130 s, it is the core phase that represents the central segment of the VR task.
- Time 3: Spanning 80 s, it is the last time related to the refinement phase in which users can refine and optimise their artworks.

To design the virtual environment, we used the Unity Engine 3D software and Meta Quest 2 as a helmet for virtual reality. Our environment consists of a simple room, in which there is just a panel (the floor on which users can walk) and four decorative torches in the corners. Our 3D objects represent multicolour geometric solids, i.e. cubes,

<sup>1</sup> A knowledge graph ([Hogan et al., 2021](#)) represents a way of organizing real-world knowledge, through nodes representing entities and links representing their relationships.

**Table 2**

The Rhodes' definition of the 4P components of creativity vs. our empirical evaluation metrics for each component, and their output data types.

Components	Rhodes' definition	Empirical evaluation	Output data types
Person	Personality traits of subjects	Self-report questionnaires (Big-Five, K-DOCS) Divergent Thinking (RAT and Rebus Puzzle)	Personality traits ( <i>Extraversion, Agreeableness, Conscientiousness, Neuroticism, Openness</i> ) rank (1–5 Likert). Creativity type ( <i>Self-Everyday, Scholarly, Mechanical/Scientific, Artistic</i> ) rank (1–5 Likert). Nine Person-oriented values are obtained.
Process	Action creative people do to build a creative product	Number of interactions within the VR environment, considering three specific phases of the creative process	Number of interactions (setting virtual objects to create an artwork) for each fixed duration phase ( <i>incipit, core, refinement</i> ). Three Process-oriented values are obtained, plus two for the <i>sum</i> and the <i>average</i> of the interactions in the phases, and a further one for the subsets of <i>high vs. low</i> interaction amount.
Product	Idea or product itself	Ontological analysis of the characteristics of virtual artworks	Ontological features (Boolean) of the artwork's subject (e.g., <i>agency, fictionality, iconicity</i> , etc.), and features (Boolean) of the artwork content ( <i>realism and connexity of parts</i> ). Thirteen Product-oriented values are obtained.
Press	Social or physical environment	Contextual auditory stimuli to modify the virtual environment	Three contextual conditions ( <i>positive stimulus, negative stimulus, no stimulus</i> ) are administered. We have one value, the condition itself.

spheres and parallelepipeds that have interactive proprieties, e.g., “grabbable” that allows users to interact and directly manipulate the objects; “changeable” that allows users to change the dimensions of the objects; and “alt physics”, by which some objects behave realistically based on principles like gravity, while other objects do not adhere to typical laws of physics.

**5. Results**

We analysed our data considering all the possible relations between the factors of the 4P theory, that is: Person - Process (1), Person - Product (2), Person - Press (3); Process - Product (4), Process - Press (5); Product - Press (6). First, we did a one-way Anova between groups to verify

differences between groups in terms of creative abilities recorded with K-DOCS. The results show no significant differences for any subscale: self-everyday creativity  $F(2, 58) = 0.684, p = 0.509$ ; scholarly creativity  $F(2,58) = 0.091, p = 0.913$ ; performance creativity  $F(2,58) = 0.334, p = 0.717$ ; mechanical/scientific creativity  $F(2,58) = 0.868, p = 0.425$ ; artistic creativity  $F(2, 58) = 0.057, p = 0.945$ . Second, we analysed the emotions expressed by participants in relation to the different auditory stimuli administered in relation to the Press. Our results show that in the positive condition participants expressed positive emotions (45 % happiness, 50 % surprise, 5 % nothing), while in the negative condition they expressed negative emotions, or none (25 % anger, 20 % disgust, 30 % fear, 25 % nothing).

**5.1. Person – process relation**

We analysed the relation between Person and Process considering the users' interactions with respect to their personality and creativity traits. We calculated the mean and median of the total interactions performed in the VR environment. The mean was 18.44 while the median was 18. We divided our total sample in two groups: low interactions ( $\leq 18$ ) and high interactions ( $\geq 19$ ). *t*-test analysis revealed a statistically significant difference between the high interaction and low interaction groups in terms of self/everyday creativity scores ( $p = 0.014, d = 0.55$ ). The high interaction group ( $M = 41.17, SD = 5.14$ ) demonstrated significantly higher creativity scores compared to the low interaction group ( $M = 38.30, SD = 5.31$ ). The effect size indicates a medium practical significance of this difference. This suggests that higher levels of interaction are associated with higher levels of self/everyday creativity.

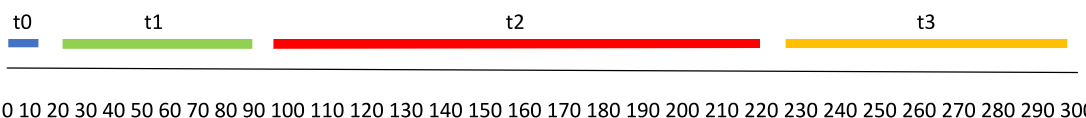
**5.1.1. Person - process, considering press subgroups**

Pearson correlations between the number of interactions and people creativity as measured by the questionnaire showed that in the positive condition (Press) there was a significant correlation between the total number of interactions (Process) within the virtual world, and both Self/Everyday creativity ( $r = 0.380, p = 0.008$ ) and Artistic creativity ( $r = 0.494, p = 0.030$ ) of the users (Person). It means that a creative Process appears related to Person dimensions (personal characteristics), and their relationship is influenced by Press dimensions. No significant correlations were found for negative and neutral conditions.

**5.2. Product – person relation**

To investigate the relations between Person and Product, we performed a *t*-test analysis of the nine personality/creativity traits vs. the thirteen ontological features. For each binary category, subjects were divided into two groups (0 = no feature or 1 = feature), and the personality traits were compared between these groups. We found that:

- People with higher levels of extroversion build artifacts that are more like containers [Group 0 ( $M = 22.86$ ) < Group 1 ( $M = 26.09$ ),  $t(50.6) = -2.117, p = 0.0377, d = 0.55$ ] and physical places [Group 0 ( $M = 22.19$ ) < Group 1 ( $M = 26.14$ ),  $t(58.0) = -2.660, p = 0.0090, d = 0.69$ ] rather than introverts people
- People with low levels of conscientiousness build scattered artworks [Group 0 ( $M = 32.83$ ) > Group 1 ( $M = 28.06$ ),  $t(25.6) = 2.692, p = 0.0097, d = 0.85$ ] more than those with low levels of conscientiousness



**Chart 1.** This chart shows the timeline of our VR task. Down the total time expressed in seconds, on the top our timeline, divided in incipit (time1), core (time2) and refinement (time3) based on the specific phases of creative process.

- People with low levels of openness build objects with specific details, for example “man with hat” or “tower with ornaments” than those low in openness [Group 0 (M = 34.11) > Group 1 (M = 30.67),  $t(6.8) = 3.775, p = 0.0016, d = 0.75$ ]
- Fictional subjects are significantly created by people with high levels of neuroticism [Group 0 (M = 27.78) < Group 1 (M = 30.67),  $t(32.2) = -2.045, p = 0.0472, d = 0.53$ ] and by people with low levels of extroversion [Group 0 (M = 25.13) > Group 1 (M = 21.00),  $t(31.6) = 2.740, p = 0.0080, d = 0.71$ ]
- People with higher levels of consciousness build more concrete [Group 0 (M = 29.05) < Group 1 (M = 32.58),  $t(38.1) = -2.220, p = 0.0305, d = 0.61$ ], than abstract artworks [Group 0 (M = 31.48) > Group 1 (M = 29.00),  $t(57.0) = 3.112, p = 0.0023, d = 0.41$ ]

5.3. Press – process relation

Concerning the relation between Press and Process, we computed the sum of interactions for each phase. T-Test analysis of the interactions (Process) with respect to the distinct conditions (Press) showed a significant difference in the number of interactions between positive vs negative condition ( $p = 0.031$ ) and between negative vs. neutral condition ( $p = 0.003$ ) at Time 1, it means that there was a higher level of interaction in the positive ( $S = 91$ ) and neutral ( $S = 97$ ) rather than the negative ( $S = 73$ ) condition.

At Time 2, there was a significant difference in the positive vs negative ( $p = 0.028$ ) and neutral ( $p = 0.025$ ) conditions. The sum of total interactions is  $S = 202$  in the positive stimulation,  $S = 162$  in the negative stimulation and  $S = 164$  in the neutral condition.

At Time 3 there was a significant difference in the positive vs neutral condition ( $p = 0.001$ ), with a sum of interactions  $S = 115$  in the positive condition,  $S = 95$  in the negative and  $S = 59$  in the neutral one.

Our analysis shows that the stimulus type has a significant impact on the interaction across different temporal phases. The positive stimulus appears most effective at maintaining a consistent engagement level, while the negative stimulus inhibits initial engagement, and the neutral one show a decline in the final phase, c.f. Table 4.

These findings show that there was a higher number of interactions in the positive condition ( $S = 387$ ) rather than in the negative ( $S = 295$ ) and in the neutral ones ( $S = 252$ ). This result suggests that the positive auditory stimulus enhanced users' interactions within the virtual environment, cf. Chart 2.

5.4. Relation product - press

To investigate the influence of Press on Product, we computed the number of artworks for each ontological feature by performing a Chi-

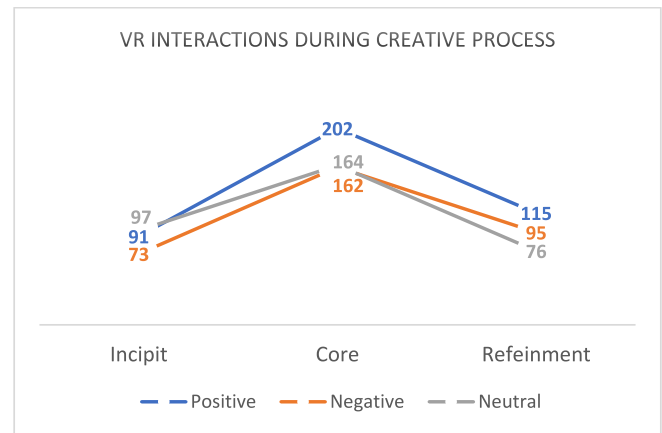


Chart 2. The distribution of interactions in our timeline for each condition (positive, negative, neutral), during the creative process.

Square analysis. No-significant results were found, however the biological category, showed the strongest trend, with positive stimuli encouraging more biological features in products compared to negative stimuli, c.f. Table 5.

5.5. Press – person Relation

Our study suggests that there is a significant relationship between Press and Person. Here we conducted test on the divergent thinking using RAT and REBUS test (Salvi et al., 2016) administrated before and after VR experience. We calculated the reaction time and the number of correct answers for each condition (positive, negative, neutral). T-test analysis shows significant improvement in the divergent thinking of our participants after VR experience. Specifically, we found:

- Increase in Rebus Puzzle correct answers in the positive stimulus condition ( $p = 0.003, d = 0.687$ )
- Increase in RAT correct answers in the negative stimulus condition ( $p = 0.038, d = 0.419$ )
- Increase in Rebus Puzzle correct answers in the neutral stimulus condition ( $p = 0.049, d = 0.388$ )

Effect sizes ranged from ( $d = 0.419$ ) to ( $d = 0.687$ ), with the largest effect observed for Rebus Puzzle performance in the positive stimulus condition. These results suggest that different stimulus types (Press) influence problem-solving performance (Person) after engaging in a creative activity.

Table 4

The t-test analysis on the difference between interaction amount in each phase, within the different contextual conditions. \* Indicates significant results.

Positive vs Negative	Mean (Pos)	Mean (Neg)	Mean Diff	t-value	df	p-value	Cohen's d
Incipit	4.55	3.65	0.90	1.814	38	0.031*	0.57
Core	10.10	8.10	2.00	1.855	38	0.028*	0.59
Refinement	5.75	4.75	1.00	1.119	38	0.131	0.35
Positive vs Neutral	Mean (Pos)	Mean (Neu)	Mean Diff	t-value	df	p-value	Cohen's d
Incipit	4.55	4.85	-0.30	-0.605	38	0.274	0.19
Core	10.10	8.20	1.90	1.898	38	0.025*	0.60
Refinement	5.75	3.80	1.95	2.826	38	0.001***	0.89
Negative vs Neutral	Mean (Neg)	Mean (Neu)	Mean Diff	t-value	df	p-value	Cohen's d
Incipit	3.65	4.85	-1.20	-2.536	38	0.003**	0.80
Core	8.10	8.20	-0.10	-0.105	38	0.459	0.03
Refinement	4.75	3.80	0.95	1.015	38	0.155	0.32

**Table 5**  
Chi-Square analysis about the relationship between Press and Product.

Category	Chi-square	df	p-value	Cramer's V	Positive %	Negative %	Neutral %
Agentive	4.230	2	0.1206	0.266	30.0 %	5.0 %	20.0 %
Functional	2.256	2	0.3237	0.194	55.0 %	75.0 %	55.0 %
Biological	5.625	2	0.0601	0.306	35.0 %	5.0 %	20.0 %
Container	0.987	2	0.6105	0.128	30.0 %	45.0 %	40.0 %
Scattered	1.905	2	0.3858	0.178	20.0 %	30.0 %	40.0 %
part/feature	2.105	2	0.3490	0.187	10.0 %	0.0 %	5.0 %
Heap	0.000	2	1.0000	0.000	0.0 %	0.0 %	0.0 %
Place	3.337	2	0.1885	0.236	40.0 %	65.0 %	40.0 %
abstract (no space-time)	1.034	2	0.5962	0.131	5.0 %	0.0 %	5.0 %
concrete (common sense)	1.950	2	0.3772	0.180	70.0 %	75.0 %	55.0 %
Iconic	0.164	2	0.9212	0.052	30.0 %	25.0 %	30.0 %
Factionary	4.800	2	0.0907	0.283	25.0 %	10.0 %	40.0 %
Autonomous	3.333	2	0.1889	0.236	40.0 %	15.0 %	35.0 %

5.6. Process – product relation

We found a significant relation between Process and Product. Given the specific metrics used for Process, the number of interactions within the virtual world is related to some features of the artwork. Our results show 4 significant correlation with a small effect size, that are: Abstract artworks ( $r = 0.229, p < 0.0001$ ); Part/feature ( $r = 0.238, p < 0.0001$ ); Fiction ( $r = -0.210, p < 0.0001$ ); Container ( $r = 0.130, p = 0.0315$ ). The positive correlations with abstract and part/feature categories suggest that these ontological features require deeper engagement; while the negative correlation with factionary features suggest that these elements may facilitate a more efficient processing.

6. Discussion

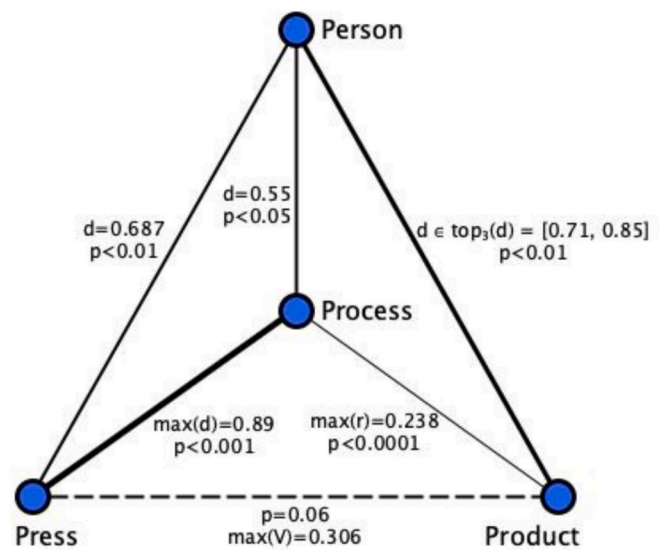
This work explored creativity by integrating different methodological approaches: explicit and implicit measures involving empirical tests, ontological analyses and virtual environments, with the aim to examine the relations between *Person* (personality traits), *Press* (stimulus context), *Process* (interaction patterns), and *Product* (ontological categories) as introduced in the 4P Theory of creativity (Rhodes, 1961).

Thus, based on the 4P Theory, we tested *Person* using self-report questionnaires on personality traits, creativity traits and emotions; *Process*, using a VR task that allow us to record the interactions of the users; *Product*, using a semi-automated ontological analysis on the characteristics of virtual artworks in terms of concreteness, animacy, categorial immateriality, functionality, fictionality, realism, topology; *Press*, changing environmental details with the use of auditory stimuli.

Our findings confirm an intricate network among the 4P components of creativity (Fig. 4): Person to Process (1), Product (2), Press (3); Process to Product (4), Press (5); Product to Press (6).

- The relation between *Person and Process*:

Our findings confirm a positive relation between Person and Process, supported by two kinds of findings. Firstly, considering the personality and creativity traits of our participants, we found that people with higher levels of Self/Everyday creativity interact more in the VR environment. It suggests that *their creative process depends on their personality*. This finding resonates with Csikszentmihalyi's (1997) concept of flow, where deep engagement facilitates creative performance. Secondly, in the positive condition (Press) subgroup there was also a significant correlation between the total number of interactions (Process) within the virtual world, and Artistic creativity of the users (Person). It suggests that *a creative process appears related to personal characteristics and is influenced by contextual conditions*. Furthermore, our findings highlight the influence of Press on the relationship between Person and Process, suggesting that a positive environment significantly impacts this relationship.



**Fig. 4.** Visual representation of the strongest observed relationships between components of Rhodes' 4P framework. Line thickness represents the strongest effect size found for each relationship (not average values) from multiple measures: Press-Process (9 measures), Press-Person (12 measures), Person-Process (1 measure), Person-Product (45 measures), Process-Product (12 measures), Press-Product (13 measures). Only for Person-Product we have shown the top-3 range due to the number of measures.

- The relation between *Person and Product*:

Our findings strongly spot the relation between Person and Product, supported by significant relations between personality traits and the features of artworks created by individuals. Individuals with higher extroversion levels tend to produce artifacts about physical places or containers, while those with lower consciousness levels tend to create scattered artworks. Conscientiousness emerged as the personality trait most frequently associated with product features, suggesting that this trait may significantly influence how individuals conceptualize and manifest creative outputs. Low levels of openness are associated with the creation of objects with specific details. The presence of fictional subjects is linked to high neuroticism and low extroversion levels. Our findings confirm that the artistic skills of individuals are linked to their personality traits, as showed in previous studies related to the analysis of artworks crafted by people with mental illness (Graham & Meng, 2011; Henemann et al., 2017), suggesting that *creative products depend on the personality of the author*.

- The relation between *Press and Process*:

Our findings confirm the relation between Press and Process. Our correlations suggest that the environmental characteristics influence the creative performance of the users. During positive stimulation, there is a notable increase in the total number of interactions with virtual objects, a trend which is also pronounced with negative stimuli, but not with neutral conditions. This aligns with the theory of Fredrickson (2004), which posits that positive emotions expand cognitive resources and exploration behaviours. Our findings suggest that *contextual stimuli prompt users to become more engaged in the creative process*, particularly during the core phase which is the most relevant phase.

- The relation between *Press and Product*:

Our results suggest a no-significant relation between Press and Product, suggesting that stimulus valence may influence Process more directly than the Product itself. However, the near-significant relationships with biological category point out a potential effect that may emerge with larger sample sizes or with more artworks. The building of just one artwork could represent an important limit in our study.

- The relation between *Press and Person*

Our study suggests that there is a relation between Press and Person as highlighted by Sternberg and Lubart (1991) and Rubenson and Runco (1992). The significant differences in RAT and Rebus test after the VR experience suggest that creative engagement may enhance cognitive capabilities. Specifically, the improvement in Rebus performance following positive stimulus supports research suggesting that positive affect enhances visual-spatial thinking and pattern recognition (Ashby & Isen, 1999), while the improvement in RAT performance following negative stimuli support research showing that certain types of negative affect can enhance analytical thinking (Forgas, 2008).

- The relationship between *Process and Product*

About the relationship between Process and Product, our results confirm the shared understanding that a creative product results from its creative process, as showed by Amabile (1996) and Batey and Furnham (2006). The ontological characteristics of creative products influence engagement patterns, with features that facilitate a rapid processing while others demand sustained attention. Specifically, products with abstract and part/feature characteristics required longer interaction, suggesting these features demand a deeper engagement; while fictional features facilitated a more efficient processing.

## 7. Conclusions

In this study we investigated relations among the 4p components of creativity outlined by Rhodes (1961). Our research is an exploratory investigation that aims to understand the creative process in a more empirical manner. To this aim, we used a Virtual Reality setup that allows users to build creative artifact without physical constraints (e.g. the dimension of 3D objects can be changed by users, as well as their position in the environment). The VR experimental setup allows us to also consider the creative *Process*, measuring the user interactions with the 3D objects in relation to a specific timeline from the identification of a task to the assessment of a generated idea. About *Product*, the virtual artifacts were evaluated using specific categories considering both the ontological features of the subject of each artwork (e.g., being agentive, functional, biological, iconic, etc.) as well as the ontological features associated with the artwork as an information entity (e.g., the realism and the topological connection of the constituent parts of the artwork). Concerning *Press*, we considered its influence in the creative performance by using positive, negative, and neutral auditory stimuli present in the environment. Last, about *Person* we recorded personality traits and creativity skills of participants. Our findings suggest an intricate

interconnection among the 4P components of creativity, with significant correlations for 5 out of 6 relations (see Fig. 4).

Our findings are in line with previous research about the relation between *Person* and *Process*, between *Person* and *Press*, and between *Process* and *Product*, and show novel insights about the relation between *Person* and *Product* and between *Press* and *Process*.

In conclusion, our findings suggest that the relations in Rhodes' 4P framework form a network in which *Process* is central, showing significant relationships with *Person*, *Press*, and *Product* dimensions. This centrality of *Process* aligns with Sawyer's (2003) view that creativity emerges through engagement and interaction rather than from static personality traits or contextual factors alone.

We have applied our method to the original 4P foundational domains, demonstrating its utility to lay a research ground to formally (via ontological distinctions) and empirically (based on explicit and implicit measures) compare creativity theories that extend 4P components with e.g., *Persuasion*, by Simonton (1990), *Potential*, by Runco (2003), *Audience* and *Affordance* from the 5 A framework (Glăveanu, 2013), *Collaboration*, *Consumption* and *Curriculum* from the 7C framework (Lubart & Thornhill-Miller, 2019), *Place* and *Passion* from the 8P framework (Sternberg & Karami, 2022), as well as frameworks that outline other dimensions of creativity, e.g., the Multi-C framework for *levels of creative expression* across development and context (Kaufman & Beghetto, 2009), the *divergence* theory of Guilford (1950), the error functionalization views (e.g., Ohlsson, 1996), the *novelty* as future value (Corazza, 2019), etc.

### CRedit authorship contribution statement

**Chiara Lucifora:** Writing – original draft, Conceptualization, Investigation. **Claudia Scorolli:** Supervision, Writing – review & editing, Conceptualization. **Aldo Gangemi:** Supervision, Conceptualization, Writing – review & editing, Formal analysis.

### Ethics approval statement

The study was approved by the Ethical committee of the University of Bologna. Number Protocol 0152607, date 06/06/2023.

### Declaration of Generative AI and AI-assisted technologies in the writing process

We did not use AI for any part of the work related to the manuscript submitted.

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### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### Data availability

Dataset is available on GitHub Repository: <https://anonymous.4open.science/r/4P-7482/>

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