Differences in creativity across Art and STEM students: We are more alike than unalike

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Abstract

The aim of the present research is to investigate creativity differences, and the magnitude and nature of those differences, among university students. More specifically, we examined differences in creativity within and between: (a) General Thematic Areas (Art and Science); (b) Specific Science domains (STEM), and; (c) Engineering micro-domains, for a total of 2277 students in German tertiary institutions. The results showed many statistically significant, but uniformly small, differences at all levels, across a range of Person, Process and Product variables. The pattern of results suggests that Openness, Creative Self-Efficacy and Divergent Thinking may be general pre-requisites for creativity. In contrast, the way that characteristics of creative products (e.g. originality) are perceived appears more complex. This research sheds additional light on long-standing debates regarding domain-generality/specificity and creativity.

1. Introduction

In the era of the Future of Work, there is now broad recognition that creativity is a vital 21st century skill (e.g. Cropley, 2019; Cropley, Cropley, & Sandwith, 2017; World Economic Forum, 2016). This is true for elementary (Vincent-Lancrin et al., 2019) and secondary education (Anwar & Aness, 2012), as much as it is true for tertiary education (e.g. Cropley, 2015; Cropley et al., 2017). However, while both the development and the application of creativity in young children appears domain-general, does creativity also change qualitatively with age (Russ & Fiorelli, 2010: p. 237). Tubb, Cropley, Marrone, Patston, and Kaufman (2020)) found some evidence supporting a positive relationship between domain-specific mathematical creativity and grade level in high school students, but is this the case more broadly? Does creativity become more domain specific as individuals move through the educational continuum, and if so, how?

This developmental trajectory of creativity is illustrated by the Four-C Model (Kaufman & Beghetto, 2009). Finding a new way to tie your shoelaces may not be novel or even very effective for other observers, but for a child, it may represent an example of the “intrapersonal insights or interpretations” (Kaufman & Beghetto, 2009: p.4) inherent in mini-c creativity. In elementary school, it may be sufficient to know that a child is, broadly speaking, creative: they are good at divergent thinking, they are willing to take risks and are open to new experiences, using these qualities to solve everyday problems creatively. However, as an individual moves from elementary to secondary and tertiary education, their experience of (and their need for) creativity seems likely to shift from purely
domain-general to include a more domain-specific element. Kaufman and Beghetto (2009: p.3) compared a shift from mini-c to little-c creativity with Amabile’s (1996) componential model, highlighting the addition of domain-relevant skills and task motivation to more domain-general creativity skills. This would seem to suggest that a creative artist differs from a creative engineer only in terms of their contrasting domain-relevant skills. Both are good divergent thinkers, both are open to new experiences and tolerant of ambiguity, and both are risk-takers, but the artist is adept at perceiving shapes and colors, while the engineer is proficient in calculus and trigonometry. Is this pattern supported by empirical evidence? As the individual moves through school and into tertiary education, developing from mini-c to little-c creativity, does a shift from domain-general to domain-specific creativity occur, and what is the nature of this shift?

Rhodes’s (1961) 4 Ps: Person, Process, Product and Press (Environment) provide a framework for exploring domain-general and domain-specific conceptualizations of creativity across the educational continuum. If creativity is domain-specific, does the creative artist differ from the creative engineer in terms of how they are (i.e. person), how they think (i.e. process), and even how they perceive creativity in artefacts (i.e. product)? Furthermore, if they exist, at what level do these differences emerge in a hierarchy of domains?

The Amusement Park Theoretical (APT: Baer & Kaufman, 2005) model of creativity illustrates this hierarchy of domains with three levels, from very broad to very specific. First are General Thematic Areas (GTA), similar to Snow’s (1959) two cultures of Art and Science. The APT model then divides these areas into Domains (e.g. Psychology or Mathematics) and then Micro-domains (e.g. Educational Psychology, Mechatronic Engineering). A key concept of the APT model is that the Person, Process and Product factors of the 4P’s framework (Rhodes, 1961) may give rise to separate patterns of individual differences across GTA, domains, and micro-domains. While there is evidence that this may hold true for GTA, and even domains, do these individuals differences persist at the level of micro-domains?

Without a clear, evidence-based understanding of the nature of creativity – domain-general or domain-specific – across the four elements of creativity (the 4 Ps), it is hard to formulate strategies for nurturing specific creative competencies through high school and into universities, at the very time that students appear to transition from a domain-general form (i.e. mini-c) into a more domain-specific form of creativity (i.e. little-c). The aim of the present research is to investigate where, in the hierarchy of the APT model, differences emerge, and the magnitude and nature of those differences, with a particular focus on tertiary Science, Technology, Engineering and Mathematics (STEM) education.

1.1. General Thematic Areas (GTA) differences

There is already a considerable body of evidence regarding similarities and differences in the General Thematic Areas of creativity (e.g. Feist, 1998; Furnham & Crump, 2013; Kaufman & Baer, 2005; Kaufman, Pumaccachua, & Holt, 2013, 2016). This evidence, perhaps not surprisingly, suggests that there are some significant differences in personal factors (i.e. the Person), how they think when they are engaged in creative problem solving (i.e. the Process), and how they perceive creativity in artefacts (i.e. the Product).

A number of studies have focused, in particular, on differences in Person and Process factors between Arts and Science (Cattell, Eber, & Tatsuoka, 1970; Furnham & Crump, 2013; Grosul & Feist, 2014; Hartlet & Greggs, 1997; Kaufman et al., 2013; Sagone & Caroli, 2012; Zare, 2011). For instance, Furnham and Crump (2013) found that art students, compared to science students, were more open, but less conscientious. Kaufman et al. (2013) found that art students were less agreeable, but reported higher self-assessed creativity, than students in science studies (e.g. chemistry, mathematics, psychology). Moreover, Sagone and Caroli (2012) found that art students generated more ideas than science students in divergent thinking (DT) tests (i.e. fluency). Sagone and Caroli (2012) found that boys attending arts schools, compared to boys attending science schools, scored higher on elaboration (i.e. the richness of detail in the ideas). We therefore hypothesized that, on a cluster of Person (i.e. personality and creative self-efficacy) and Process (i.e. divergent thinking) variables, there will be statistically significant differences between Art and Science students (H1a).

In addition, the present study also explored Product differences across GTA. Artists, on the one hand, create artefacts including, for example, sculptures, paintings, and drawings. For artists, novelty (or originality) and aesthetic qualities (e.g. beauty) are important in determining the success of their products. By contrast, science – or STEM disciplines more specifically – revolve around the development of (technological) solutions in response to an identified need. In this area, the feasibility of a solution, and its effectiveness, are as important as originality (see Copley & Kaufman, 2012; Copley, Kaufman, & Copley, 2011 for a more detailed discussion). We therefore hypothesized that Art students will associate novelty (originality) with creativity more strongly than Science students (H1b), and, that Science students will associate feasibility and effectiveness with creativity more strongly than Art students (H1c).

1.2. Domain differences in STEM

Studies of GTA, not surprisingly, define Science extremely broadly, lumping together everything from physics to medicine. Detecting where differences in Person, Process and Product may emerge (or disappear) requires a shift deeper into the hierarchy of the APT model. Prior research has focused on specific domains such as medicine or economics (Eisenman, 1969; Lievens, Coetsier, De Fruyt, & De Maeseneer, 2002; Lounsbury, Smith, Levy, Leong, & Gibson, 2009; Marrs, Barb, & Ruggiero, 2007; Pringle, DuBose, & Yankey, 2010). Pringle et al. (2010), for example, compared eight different business domains (e.g. accounting, marketing, economics) and found that marketing majors were the most extraverted compared to any other major, with no significant differences in creativity across the business majors.

While there has long been recognition that the GTA of Science involves abundant creative thought (e.g. Curtin, 1982; Simonton, 2004, 2009; Tauber, 1996; Wechsler, 1979), key domains within this thematic area – Science, Technology, Engineering and Mathematics (STEM) – have been neglected by researchers (Dexter & Kozbelt, 2013; Kozbelt, Dexter, Dolose, & Seidel, 2012). An exception is
kline and Lapham (1992) who compared art, social science, science and engineering students on personality. They found significant differences not only between GTA (i.e. art versus science/engineering students), but also between the “science” domains, with (natural) scientists scoring higher on conscientiousness than engineers, who scored higher than social scientists. This relative lack of research regarding differences between STEM domains is important, given the fact that these occupations are expected both to grow strongly (Hawksworth, Berriman, & Goel, 2018; International Labour Organization, 2017) and are least likely to be replaced by automation in the era of the Fourth Industrial Revolution (Industry 4.0) and the Future of Work (Bakhshi, Downing, Osborne, & Schneider, 2017; Frey & Osborne, 2017). Drawing on the limited research, we hypothesized that, on the cluster of Person (i.e. personality and creative self-efficacy) and Process (i.e. divergent thinking) variables, there will be statistically significant differences between students in the four STEM domains (H2a).

Following the study of differences in GTA, we also explored Product differences between STEM domains. Natural sciences focus on knowledge development, while engineering and technology are concerned with needs-driven problem solving. Effectiveness and feasibility, as explained previously, are central to creativity in needs-driven problem solving. In contrast, knowledge creation in natural sciences may not be bound by the same imperative, with novelty and elegance, like the artist, possibly of greater importance as components of creativity. We hypothesized, therefore, that natural science students will associate feasibility and effectiveness with creativity less strongly than technology and engineering students (H2b). In addition, creativity in mathematics manifests itself in theoretical contributions where practical feasibility may play a less important role. In contrast, creative products in natural science, engineering, and technology must be not only original, but also feasible. Therefore, we expect that mathematics students will associate feasibility with creativity less strongly than natural science, technology, and engineering students (H2c).

1.3. Micro-domain differences in STEM

Notwithstanding any observed differences between GTA and STEM domains, detecting where differences in Person, Process and Product may arise between micro-domains is vital in translating findings into useful guidance for secondary and tertiary educators. In practical terms, more students might be torn between studying a micro-domain of engineering than students debating between pursuing a career in engineering versus art. Therefore, we also investigated differences between the micro-domains of Engineering (i.e. industrial, electrical, mechanical and civil engineering).

Only a handful of studies has examined creativity differences by micro-domains. Agogué, Le Masson, Dalmaso, Houdé, and Cassotti (2015) investigated how industrial designers and engineers perform on divergent thinking (DT) tests (specifically, on fluency). They found that industrial designers generated more ideas than engineers did. Another recent study investigated whether ratings of product creativity differed between industrial designers and engineers (Cropley & Kaufman, 2019). They found that industrial designers rated the aesthetic quality of products higher than engineers, while they found no differences for the rating of the functionality of products.

These observed differences, however, may result from the fact that industrial design is distinctly different from engineering – i.e. they are not closely related micro-domains? Industrial design may be said to originate from art, while engineering is grounded in the physical sciences. The comparison may be therefore at the level of domain or even GTA, rather than of micro-domains. Comparisons of the more closely, and clearly, related micro-domains of engineering may provide more valuable insights for the debate on the domain generality or domain specificity of creativity. As such, the current study will compare four micro-domains of engineering: industrial, electrical, mechanical and civil engineering.

As related micro-domains, all are concerned with the development of technological solutions in response to an identified need. However, different engineering micro-domains might differ in the type of problems they solve, or even in the way they would solve the same problem (Bruch & Krieshok, 1981; Veurink & Hamlin, 2011; Veurink & Sorby, 2013). For instance, electrical engineers design, develop, and test electrical power systems (e.g. motors) and electronic devices (e.g. microprocessors). Mechanical engineers design, develop, and test power-producing systems such as internal combustion engines. Civil engineers design, develop, and test structures in the built environment (e.g. bridges). Industrial engineering, somewhat in contrast, is concerned with the design, development and testing of integrated systems of people, materials, equipment, and energy. A difference between these closely related micro-domains might be that electrical, mechanical and civil engineers foster advances through innovative new technologies, while industrial engineers apply those new technologies (Kimbler, 1995).

Nazzal (2015) has investigated how civil, chemical, manufacturing, electrical, mechanical, transport systems and environmental engineering differed across the stages of the creative problem-solving process (i.e. problem recognition, idea generation, idea evaluation, and idea selection). The study found no differences between engineering micro-domains on idea generation and idea evaluation. However, students in chemical, environmental, and transport systems engineering selected more creative ideas than students in civil, mechanical, and manufacturing engineering.

Drawing on the limited available research, we hypothesized that on the cluster of Person (i.e. personality and creative self-efficacy) and Process (i.e. divergent thinking) variables, there will be statistically significant differences between four micro-domains of engineering (i.e. industrial, electrical, mechanical and civil engineering) (H3a).

The present study also examined Product creativity differences between the micro-domains in question. The focus on the implementation and use of developed technologies in industrial engineering implies that this micro-domain is more strongly user-centric than electrical, mechanical and civil engineering (Brawner, Camacho, Lord, Long, & Ohlund, 2012; Kimbler, 1995). Consequently, it may be that novelty (originality) and aesthetic qualities (e.g. beauty), are more significant for industrial engineers, whose task is not only to implement a solution that works (effectiveness/feasibility), but one that meets underlying expectations for improvement or advancement (i.e. novelty), and is also complete, pleasing and user-friendly (i.e. elegant). We hypothesized that industrial engineering
students will associate novelty (originality) more strongly with creativity than electrical, mechanical and civil engineering students (H3b).

2. Method

2.1. Participants

A total of 2277 undergraduate and graduate students (1052 females; 1225 males) aged between 17 and 37 (mean = 23.02; SD = 3.30) participated in this study. The students were enrolled in universities or universities of applied sciences across Germany. 130 participants (91 females; 39 males) were enrolled in an Art degree, while 2147 participants (961 females and 1186 males) were enrolled in a STEM domain (i.e. science, technology, engineering or mathematics).

Of the students enrolled in STEM domains, 665 participants (420 females; 245 males) were enrolled in a natural science degree (e.g. biology, physics); 461 participants (172 females; 289 males) were enrolled in a technology degree (i.e. computer science); 876 participants (280 females; 596 males) were enrolled in an engineering degree (e.g. civil engineering, mechanical engineering), and 145 participants (89 females and 56 males) were enrolled in a mathematics degree.

In the Engineering micro-domains, 233 participants (91 females; 142 males) were enrolled in industrial engineering; 168 participants (37 females; 131 males) were enrolled in electrical engineering; 311 participants (76 females; 235 males) were enrolled in mechanical engineering, and 164 participants (76 females; 88 males) were enrolled in civil engineering.

2.2. Measures

The current study was part of the 12th round of the survey-based research project "Fachkraft 2030" which took place in March 2018. The survey is conducted by Maastricht University in cooperation with Studitemps GmbH. The survey consisted of questions about students' study experiences, participation in student jobs and future career expectations. At the end of the questionnaire, students could participate in a variety of psychological tasks (e.g. personality and creativity). Three Ps from Rhodes (1961) were measured in this study: Person (i.e. personality and creative self-efficacy), Process (i.e. divergent thinking), and Product (i.e. ratings of solutions on their creativity).

2.2.1. Person

Personality was measured using the 50-item version of the International Personality Item Pool (IPIP; Goldberg et al., 2006). For each personality trait, participants received ten statements (presented in a random order). Sample statements include: “I enjoy hearing new ideas” and “I am always prepared”. Participants rated how well each statement describes themselves on a Likert scale, ranging from 1 (very inaccurate) to 5 (very accurate). Scale reliabilities (Cronbach’s alpha) were strong: openness (α = .82), conscientiousness (α = .81), extraversion (α = .86), agreeableness (α = .77), neuroticism (α = .86). Second, creative self-efficacy (CSE) was measured using the three-item scale of Beghetto (2006). The three items are: “I am good at coming up with new ideas”, “I have a lot of good ideas”, and “I have a good imagination”. Participants rated to what extent they disagreed or agreed with each item on a Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Scale reliability (Cronbach’s alpha) was good (α = .72).

2.2.2. Process

Divergent thinking (DT) was assessed by asking participants to generate ideas for a function-first or form-first divergent thinking task. In total, six different tasks were randomly distributed over the questionnaire. Each participant was asked to generate ideas for one divergent thinking task (no time limit). For the function-first task, participants were asked to generate as many ideas they could for one the following problems: ‘How to improve the use of public trains’, ‘How to protect the environment’, ‘How to make waiting time at cash desks more bearable’, or ‘How can you make teaching in your university better’ (see Baas, Dreu, & Nijstad, 2011; de Buisonj, Ritter, de Bruin, ter Horst, & Meeldijk, 2017; Ritter, van Baaren, & Dijksterhuis, 2012). For the form-first task, participants were asked to generate as many different and unusual uses as they could for a newspaper or a brick, as examples of the Alternate Uses Task (AUT: Guilford, 1967). Participants’ responses were counted to produce a fluency score. Fluency has been used as a measure of creative potential in many studies (Batey & Furnham, 2008; Batey, Chamorro-Premuzic, & Furnham, 2009; Tsakanikos & Claridge, 2005). In addition, the average number of characters used per idea was counted to produce an elaboration score. Neither the flexibility nor the originality of ideas was measured: the total number of ideas generated (6654) exceeding what could be rated in this study.

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1 Universities are theory and research-oriented while universities of applied sciences are more practical and profession-oriented.

2 Function-first problems state the desired outcome, e.g. “How to transport baked beans?” for which solutions are sought. Form-first problems, in contrast, state the solution, e.g. “A Tin Can” and seek different possible uses. The former is more representative of real-world problem-solving (see Cropley et al., 2017).
2.2.3. **Product**

Participants were presented with four solutions\(^3\) for one of the following problems: (a) how to improve the use of public trains, or; (b) how to protect the environment (see Baas et al., 2011; de Buissonjé et al., 2017 for more information). They were first asked to rate the “overall creativity” of each solution on a Likert scale ranging from 1 (not at all creative) to 5 (very creative). Next, in a random order, participants were asked to rate the solutions according to the “originality”, “feasibility”, and “effectiveness” of each idea, also on Likert scales ranging from 1 (not at all original/feasible/effective) to 5 (very original/feasible/effective).\(^4\)

3. **Results**

Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted. In addition, the inter-item correlations of the dependent variables were used: (a) **Person**, including openness, conscientiousness, extraversion, agreeableness, neuroticism, and creative self-efficacy, and; (b) **Process**, including divergent thinking (i.e. fluency and elaboration). To test hypothesis 1a, we conducted a MANCOVA analysis where the independent variable (factor) was GTA (art versus science). To test hypothesis 2a, we performed a MANCOVA analysis where the four domain categories were included as the fixed factor (i.e. STEM: natural science, technology, engineering and mathematics). For hypothesis 3a, we conducted a MANCOVA analysis where the four micro-domain categories were included as the fixed factor (i.e. industrial, electrical, mechanical and civil engineering). Following each MANCOVA analysis, a series of univariate, one-way ANCOVAs were performed in order to explore the results for the dependent variables separately, using a Bonferroni correction to control for potential Type I error (Tables 1 and 2).\(^5\) Age and gender were held constant in both the MANCOVA and ANCOVA analyses.

Next, a distinction was made for the function-first and form-first divergent thinking tasks to explore whether differences in divergent thinking (i.e. Process) emerge for both tasks, or only one of them (Table 2). To this end, MANCOVA and ANCOVAs were performed in which age and gender held constant.

In addition to creativity differences in Person and Process, the present study also explored Product creativity differences across General Thematic Areas, Domains and Micro-domains. To test these hypotheses (H1b, H1c, H2b, H2c and H3b), a Fisher r-to-z-transformation was performed, assessing the significance of the difference between the correlation coefficients for the independent variables of GTA, Domain, and Micro-domain (Tables 3 and 4).

3.1. **General Thematic Areas (GTA) differences**

The one-way MANCOVA suggested that there was a significant difference between art and science students on the combined dependent variables, \(F(1, 2,275) = 12.15, p < .001\), Wilk’s Lambda = .95, partial \(\eta^2 = .051\) (after controlling for age and gender). Hence, hypothesis H1a was supported.

To explore the results for the dependent variables separately, univariate one-way ANCOVAs were conducted. There were significant differences at the \(p < .0063\) for openness (\(F(1, 2,255) = 36.47, p = .000\), partial \(\eta^2 = .016\)), agreeableness (\(F(1, 2,255) = 14.71, p = .000\), partial \(\eta^2 = .007\)), creative self-efficacy (\(F(1, 2,255) = 28.15, p = .000\), partial \(\eta^2 = .012\)), and fluency (\(F(1, 2,255) = 32.24, p = .000\), partial \(\eta^2 = .014\)). An inspection of the mean scores (see Tables 1 and 2) shows that art students reported higher levels, compared to science students, of: (a) openness (art: \(M = 3.82, SD = 0.05\); science: \(M = 3.54, SD = 0.05\)); (b) agreeableness (art: \(M = 4.15, SD = 0.13\); science: \(M = 3.86, SD = 0.14\)); (c) creative self-efficacy (art: \(M = 4.03, SD = 0.04\); science: \(M = 3.70, SD = 0.05\)); and, (d) fluency (art: \(M = 4.13, SD = 0.08\); science: \(M = 2.62, SD = 0.09\)).

To further explore hypothesis 1a, we also made a distinction for the function-first and form-first divergent thinking tasks. The one-way MANCOVA suggested that there was a significant difference between art and science students on the combined dependent variables (i.e. fluency and elaboration) for the function-first task: \(F(1, 4,492) = 10.86, p < .001\), Wilk’s Lambda = .97, partial \(\eta^2 = .028\); and the form-first task: \(F(1, 781) = 8.93, p < .001\), Wilk’s Lambda = .96, partial \(\eta^2 = .044\) (after controlling for age and gender). Consequently, univariate, one-way ANCOVAs showed that there was only a significant difference at the \(p < .0063\) in fluency for the function-first task (see Table 2): Art students reported a higher level of fluency (\(M = 3.74, SD = 0.02\)) than science students (\(M = 2.17, SD = 0.04\)).

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\(^3\) Prior to this study, Dutch undergraduate students were asked to generate ideas to improve the use of public trains or to protect the environment. A list of 39 unique solutions for each problem were rated by creativity experts and resulted in a high interrater reliability between the experts (see Online Supplementary Material).

\(^4\) Originality is the extent to which the solution is novel, out of ordinary. Feasibility is the ease with which the solution can be implemented (given the current context such as financial resources, infrastructure, time required, legal issues etc.). Effectiveness is the extent to which the solution helps to solve the problem.

\(^5\) It can be argued that there are eight tests of significance (not counting those for the intercept and control variables), so p-values more than 0.05/8 = 0.0063 should be declared insignificant at the 5% level.
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Mean personality traits (Big 5) and creative self-efficacy (CSE) scores per GTA, Domain and Micro-domain.

Table 1

| GTA        | Openness | Conscientiousness | Extraversion | Agreeableness | Neuroticism | CSE |
|------------|----------|-------------------|--------------|---------------|-------------|-----|
|            | M (SD)   | M (SD)            | M (SD)       | M (SD)        | M (SD)      | M (SD) |
| Art        | 3.82* (0.05) | 3.33 (0.03)       | 3.11 (0.03)  | 4.15* (0.13)  | 2.91 (0.17) | 4.03* (0.04) |
| Science    | 3.54* (0.05) | 3.42 (0.03)       | 3.05 (0.04)  | 3.86* (0.14)  | 3.12 (0.18) | 3.70* (0.05) |
| Total      | 3.56 (0.08) | 3.42 (0.04)       | 3.05 (0.04)  | 3.88 (0.15)   | 3.11 (0.19) | 3.72 (0.09)  |
| Domain     |          |                   |              |               |             |     |
| Science    | 3.61* (0.06) | 3.36* (0.04)     | 3.07* (0.04) | 3.97* (0.12)  | 3.04 (0.18) | 3.67 |
| Technology | 3.51* (0.06) | 3.36* (0.04)     | 2.89* (0.04) | 3.77* (0.12)  | 3.11 (0.18) | 3.70 |
| Engineering| 3.50* (0.06) | 3.49* (0.04)     | 3.12* (0.04) | 3.81 (0.11)   | 3.19 (0.17) | 3.73 |
| Mathematics| 3.60 (0.06) | 3.49 (0.04)      | 3.00 (0.04)  | 3.98 (0.12)   | 3.08 (0.18) | 3.63 |
| Total      | 3.54 (0.05) | 3.42 (0.03)       | 3.05 (0.04)  | 3.86 (0.14)   | 3.12 (0.18) | 3.70 (0.05) |
| Micro-domain |          |                   |              |               |             |     |
| Industrial engineering | 3.51 (0.06) | 3.53 (0.02)     | 3.23* (0.06) | 3.91* (0.08)  | 3.17 (0.19) | 3.66 |
| Electrical engineering | 3.46 (0.05) | 3.42 (0.02)     | 3.11 (0.06)  | 3.70 (0.08)   | 3.24 (0.16) | 3.64 |
| Mechanical engineering | 3.52 (0.05) | 3.49 (0.02)     | 3.05 (0.06)  | 3.76 (0.08)   | 3.19 (0.16) | 3.81 |
| Civil engineering | 3.49 (0.05) | 3.51 (0.02)     | 3.14 (0.06)  | 3.86 (0.09)   | 3.15 (0.19) | 3.76 |
| Total      | 3.55 (0.05) | 3.42 (0.03)       | 3.06 (0.04)  | 3.82 (0.13)   | 3.16 (0.17) | 3.71 (0.04) |

* Significant difference (p < .0063) between bolded asterisked score and asterisked score. Note: O = Openness, C = Conscientiousness, E = Extraversion, A = Agreeableness, N = Neuroticism, CSE = Creative self-efficacy, M = Mean, SD = Standard Deviation. Age and gender were held constant.

SD = 0.02). However, it is important to note that the difference between art and science students on the form-first task was close toward significance (p = .0668).

To test the hypotheses concerning product differences and GTA (H1b and H1c), correlations (Table 3) suggested that art students associate originality with creativity (r = .675, p < .001) more strongly than do science students (r = .543, p < .001). This difference (Table 4) between art and science students is significant (z = 2.32; p < .05) with a small effect size (Cohen’s d = .21). Hence, hypothesis H1b was supported. In comparison, science students associate feasibility (r = .164, p < .001) and effectiveness (r = .323, p < .01) with creativity more strongly than do art students (r = .124, p > .05, and r = .311, p < .001 respectively). However, these differences between art and science students were not significant (Table 4). Hence, hypothesis H1c was not supported.

3.2. Domain differences in STEM

The one-way MANCOVA with domains as the factor suggested that there were significant differences between the domains of natural science, technology, engineering and mathematics (i.e. STEM) on the combined dependent variables, F(3, 2,143) = 12.61, p < .001, Wilk’s Lambda = .84, partial η² = .057 (after controlling for age and gender). Hence, there was support for hypothesis H2a.

To explore the results for the dependent variables separately, univariate one-way ANCOVAs were conducted. There were significant differences in openness at the p < .0063 for science versus technology: F(1, 2,123) = 11.45, p = .001, partial η² = .005; and science versus engineering: F(1, 2,123) = 20.40, p = .001, partial η² = .010. In addition, there were significant differences in conscientiousness at the p < .0063 for engineering versus science: F(1, 2,123) = 22.41, p = .000, partial η² = .011; and engineering versus technology: F(1, 2,123) = 15.38, p = .000, partial η² = .007. Moreover, there were significant differences in extraversion at the p < .0063 for technology versus science: F(1, 2,123) = 18.08, p = .000, partial η² = .008; and technology versus engineering: F(1, 2,123) = 28.45, p = .000, partial η² = .013. Additionally, there were significant differences in agreeableness at the p < .0063 for science versus technology: F(1, 2,123) = 13.38, p = .000, partial η² = .006. There were also significant differences in elaboration at the p < .0063 for science versus engineering: F(1, 2,123) = 12.94, p = .000, partial η² = .006. Finally, there were significant differences in fluency at the p < .0063 for science versus technology: F(1, 2,123) = 18.19, p = .000, partial η² = .009; and science versus engineering: F(1, 2,123) = 19.49, p = .000, partial η² = .009.

An inspection of the mean scores (Tables 2 and 3) shows that natural science students reported higher levels, compared to technology students, of: (a) openness (science: M = 3.61, SD = 0.06, technology: M = 3.51, SD = 0.06); (b) extraversion (science: M = 3.07, SD = 0.04, technology: M = 2.89, SD = 0.04); (c) agreeableness (science: M = 3.97, SD = 0.12, technology: M = 3.77, SD = 0.12), and; (d) fluency (science: M = 3.08, SD = 0.05, technology: M = 2.34, SD = 0.06). In addition, natural science students reported higher levels, compared to engineering students, of: (a) openness (science: M = 3.61, SD = 0.06, engineering: M = 3.50, SD = 0.06); (b)
fluence (science: $M = 3.08, SD = 0.05$, engineering: $M = 2.46, SD = 0.05$), and; (c) elaboration (science: $M = 44.64, SD = 3.38$, engineering: $M = 36.98, SD = 3.27$). Lastly, natural science students reported higher levels of fluency ($M = 3.08, SD = 0.05$) than mathematics students ($M = 2.35, SD = 0.06$). Engineering students reported higher levels, compared to technology students, of: (a) conscientiousness (engineering: $M = 3.49, SD = 0.04$, technology: $M = 3.36, SD = 0.04$), and; (b) extraversion (engineering: $M = 3.12, SD = 0.04$, technology: $M = 2.89, SD = 0.04$). In addition, engineering students reported higher levels of conscientiousness ($M = 3.49, SD = 0.04$) than natural science students ($M = 3.36, SD = 0.04$).

To further explore hypothesis 2a, we also made a distinction for the function-first and form-first divergent thinking tasks. The one-way MANCOVA suggested that there were significant differences between STEM domains on the combined dependent variables (i.e. fluency and elaboration) for the function-first task: $F(1, 1,402) = 14.81, p < .001$, Wilk’s Lambda = .88, partial $\eta^2 = .046$; and the form-first task: $F(1, 737) = 6.91, p < .001$, Wilk’s Lambda = .90, partial $\eta^2 = .041$ (after controlling for age and gender). Consequently, univariate one-way ANCOVAs showed that there were significant differences in fluency for both the function-first and form-first divergent thinking task (Table 2). Natural science students reported a higher level of fluency for function-first ($M = 2.58, SD = 0.03$) than technology ($M = 1.78, SD = 0.03$) and engineering students ($M = 2.08, SD = 0.03$). However, for the form-first task, natural science students ($M = 4.08, SD = 0.09$) reported a higher level of fluency only compared to engineering students ($M = 3.16, SD = 0.10$). In addition, natural science students ($M = 54.20, SD = 4.11$) only reported a higher level of elaboration for the function-first task than engineering students ($M = 44, SD = 3.97$).

To test the hypotheses concerning product differences and domains (H2b and H2c), correlations (Table 3) suggested that natural science students ($r = 0.161, p < .001$) associate feasibility with creativity less strongly than do technology ($r = 0.184, p < .001$) and engineering students ($r = 0.180, p < .001$). Neither the difference (Table 4) between natural science and technology students is significant, $z = -0.39, p > .05$ nor between natural science and engineering students ($z = -0.38, p < .001$). However, as expected, natural science students ($r = 0.245, p < .001$) associated effectiveness with creativity less strongly than technology ($r = 0.409, p < .001$) and engineering students ($r = 0.340, p < .001$). The difference between natural science and technology students is significant ($z = -3.03, p < .01$) as well as that between natural science and engineering students ($z = -2.02, p < .05$). However effect sizes for both (Cohen’s $q$) were small ($q = .18$ and $q = .10$ respectively). Hence, hypothesis H2b was only supported for effectiveness.

In addition (Table 3) students in mathematics ($r = 0.013, p > .05$) associated feasibility with creativity less strongly than natural science ($r = 0.161, p < .001$), technology ($r = 0.184, p < .001$) and engineering students ($r = 0.180, p < .001$). The difference (Table 4) between mathematics and technology students is significant ($z = 2.07, p < .05$), as is that between mathematics and engineering students ($z = 2.17, p < .05$), with small effect sizes (Cohen’s $q = .17$ for both). However, the difference between mathematics and natural science students was not significant ($z = 1.90, p = .057$). Hence, there was partial support for hypothesis H2c.
3.3. Micro-domain differences in engineering

The one-way MANCOVA with micro-domains as the factor suggested that there were significant differences between the micro-domains of Engineering (i.e. industrial, electrical, mechanical and civil engineering) on the combined dependent variables, \( F(3, 872) = 2.69, p < .001 \), Wilk’s Lambda = .91, partial \( \eta^2 = .031 \) (after controlling for age and gender). Hence, there was support for hypothesis H3a.

To explore the results for the dependent variables separately, univariate one-way ANCOVAs were conducted. There were statistically significant differences in extraversion at the \( p < .00063 \) for industrial versus mechanical engineering: \( F(1, 853) = 11.60, p = .001 \), partial \( \eta^2 = .01 \); and in agreeableness for industrial versus electrical engineering: \( F(1, 853) = 9.01, p = .003 \), partial \( \eta^2 = .010 \). An inspection of the mean scores (Table 1) shows that industrial engineering students reported a higher level of extraversion (\( M = 3.23, SD = .06 \)) than mechanical engineering students (\( M = 3.05, SD = .06 \)). In addition, industrial engineering students reported a higher level of agreeableness (\( M = 3.91, SD = .08 \)) than electrical engineering students (\( M = 3.70, SD = .08 \)).

To further explore hypothesis 3a, we also made a distinction for the function-first and form-first divergent thinking tasks. The one-way MANCOVA suggested that there were significant differences on the combined dependent variables (i.e. fluency and elaboration) for the function-first task: \( F(1, 567) = 2.61, p < .01 \), Wilk’s Lambda = .95, partial \( \eta^2 = .021 \); and the form-first task: \( F(1, 301) = 2.25, p < .01 \), Wilk’s Lambda = .92, partial \( \eta^2 = .033 \) (after controlling for age and gender). However, these differences did not reach statistical significance according to the Bonferroni correction (\( p < .0063 \)) in the univariate one-way ANCOVAs (see Table 2). Hence, hypothesis 3a was not supported when the distinction for function-first and form-first divergent thinking tasks was made.

To test the hypotheses concerning product differences and domains (H3b), correlations (Table 3) indicated that industrial engineering students (\( r = 0.481, p < .001 \)) associate originality with creativity more strongly than do students in civil engineering (\( r = 0.477, p < .001 \)), but less strongly than electrical engineering (\( r = 0.658, p < .001 \)) and mechanical engineering students (\( r = 0.567, p < .001 \)).
Table 5
Overview of the hypotheses in this study.

| Hypotheses | p-value | Effect size | Supported/Rejected | vs. |
|------------|---------|-------------|--------------------|-----|
| GTA        |         |             |                    |     |
| H1a        | $p < .001$ | $\eta^2 = .051$ | Supported           |     |
| H1b        | $p < .05$  | $q = .211$  | Supported           |     |
| H1c        | $p > .10$  | $-\quad$    | Rejected            |     |
| Domain     |         |             |                    |     |
| H2a        | $p < .001$ | $\eta^2 = .057$ | Supported           |     |
| H2b        | $p > .05$  | $-\quad$    | Rejected            | technology |
| H2c        | $p > .05$  | $-\quad$    | Rejected            | engineering |
| Micro-domain |      |             |                    |     |
| H3a        | $p < .001$ | $\eta^2 = .031$ | Supported           |     |
| H3b        | $p < .01$  | $q = .265$  | Opposite direction  | electrical |
|            | $p > .05$  | $-\quad$    | Rejected            | mechanical |
|            | $p > .05$  | $-\quad$    | Rejected            | civil    |
Neither the difference (Table 4) between industrial engineering and civil engineering ($z = -0.05, p > .05$), nor that between industrial engineering and mechanical engineering ($z = 1.36, p > .05$) is significant. However, in contrast to our expectations, the difference between industrial engineering and electrical engineering is significant ($z = 2.60, p < .01$) with a small effect size (Cohen’s $q = .26$). Hence, hypothesis H3b was not supported.

Table 5 presents an overview of the tested hypotheses in this study.

4. Discussion

4.1. Person

In line with previous research, the results of this study indicate clear differences at the level of General Thematic Areas (GTA). Art students are different from Science students in terms of personality. Broadly speaking, Art students are more open to new experiences, more agreeable (see also Feist, 1998) and have a higher Creative Self-Efficacy (CSE: see also Furnham, Batey, Booth, Patel, & Lozinskaya, 2011) than their Science counterparts. Importantly, however, effects sizes in the present study suggest that these differences, while statistically significant, are small. Coupled with the present study’s finding of no statistically significant differences on extraversion, conscientiousness and neuroticism at the level of GTA, this supports the notion of elements of Person as general pre-requisites for creativity in any area (Baer & Kaufman, 2005; Kaufman & Baer, 2005). Openness and CSE, therefore, support creativity for the Artist as much as they do for the Scientist. At this level (GTA) and for this factor (Person), educational support for creativity should foster openness and CSE as broadly as possible, from Kindergarten through to University education. It is important to note here that we confine our discussion to those aspects of the Person known to correlate to creativity, i.e. openness and creative-self efficacy (e.g. Batey & Furnham, 2006; Tierney & Farmer, 2002). Although the current study indicated a statistically significant difference in agreeableness at the level of GTA, the lack of any association of this factor with creativity (Batey et al., 2009) places it outside the scope of this discussion.

The current interest in STEM education, the digitalization at the heart of Industry 4.0, and the focus on key skills as an element of the Future of Work, provides a rationale for turning attention specifically to the domains that comprise STEM. The APT model suggests that if elements of personality are general pre-requisites for creativity across thematic areas, then they should remain general pre-requisites at the more specific level of domains. Openness, in other words, should remain a correlate for creativity for natural scientists, technologists, engineers and mathematicians, as much as it is a general pre-requisite for artists.

In the present study, some relevant personality differences are apparent among these four thematically related domains. Natural science students, for example, are more open to new experiences than technology and engineering students. Engineering students were more conscientious than natural science and technology students (we introduce this factor at the level of domains because there is support (Batey & Furnham, 2006) for its association with creativity). However, these significant differences were even smaller in magnitude than those observed at the level of GTA, supporting the role of openness and creative self-efficacy as general pre-requisites for creativity. This finding then adds weight to the importance of broad educational support for these Person factors of creativity, from Kindergarten to University.

Although the results for GTA and the STEM domains suggest that any difference on the factor Person diminishes the deeper we proceed into this hierarchy, the present study, nevertheless, compared four Engineering micro-domains (i.e. industrial, electrical, mechanical and civil engineering). No statistically significant differences on openness, conscientiousness, neuroticism or CSE were observed at this level. The small differences between artists and scientists became even smaller between STEM domains, and disappeared completely, in statistical terms, at the level of Engineering micro-domains. Openness and CSE remain general pre-requisites for creativity. This result adds further weight to the need for broad educational support, now more specifically at tertiary level, for the Person factors that are linked to creativity.

4.2. Process

As with Person, hypothesized differences in Divergent Thinking (DT) – the core cognitive process associated with creativity – were found between the GTA under investigation. Art students, in this case, showed statistically significant, higher levels of fluency, both in general, and for function-first problems. However, as was the case for openness and CSE (i.e. Person factors), these differences remain small as determined by effect size. Coupled with the fact that there was no statistically significant difference between Art and Science students on elaboration, a case can be made that Divergent Thinking is also a general pre-requisite for creativity. The results for DT on the function-first and form-first tasks support this conclusion, with a statistically significant, but small, difference between art and science students only on fluency (Function-First task).

Turning to the more specific STEM domains, statistically significant differences emerged on general fluency between natural science students and technology, engineering, and mathematics students. For elaboration, a statistically significant difference was found between natural science and engineering. Differences were also noted for the function-first and form-first DT tasks. In all cases, however, the differences showed effect sizes even smaller than those between GTA. In practical terms, therefore, these differences were not meaningfully present between STEM domains, further supporting a divergent thinking as a general pre-requisite for creativity.

Proceeding to the level of micro-domains, the present study found no statistically significant differences on fluency or elaboration either in general, or for the function- and form-first tasks. Whether industrial engineer, electrical engineer, mathematician, natural scientist or artist, divergent thinking – a defining element of creativity – appears to be present to a statistically similar degree. The implications for elementary, secondary and tertiary education are therefore similar to those discussed for openness and CSE. Divergent
thinking is a key domain-general creativity skill.

4.3. Product

In addition to differences on Person and Process, this study explored differences in how individuals perceive the qualities of a creative product across GTA, domains and micro-domains. Specifically, the degree to which individuals associate a product’s originality, feasibility and effectiveness with creativity were examined.

At the level of GTA, both art and science students strongly associated originality (novelty) with creativity, with correlation coefficients >.500. This strong association was greater among art students compared to science students, with the difference in correlation coefficients statistically significant. The magnitude of this difference, however, was small. Both art and science students moderately associated effectiveness with creativity, with no statistical difference between these thematic areas. Feasibility was weakly associated with creativity, also with no statistical difference between art and science students. Broadly speaking, and consistent with the findings for Person and Process, there is little practical difference in the way art and science students perceive product creativity or associate key product qualities with creativity. Both, it can be said, see originality as central to defining the creativity of a product, with effectiveness also moderately important. This is consistent with mainstream views in creativity research (Sternberg, Kaufman, & Pretz, 2002, Cropley & Kaufman, 2012).

At the level of STEM domains, this pattern of associations remains the same. The four STEM domains associate originality with product creativity strongly, with some statistically significant, but small, differences between domains. Effectiveness has a moderate association with product creativity, also with some significant, but small, differences. Finally, feasibility is weakly associated with product creativity, with the exception of mathematics students. Mathematicians indicated no association between feasibility and product creativity, although the magnitude of the difference between them and the other STEM disciplines was very small. Notwithstanding the small effect sizes for the inter-domain differences, engineering and technology students in general indicated stronger associations of all three product qualities with creativity, compared to natural science and mathematics students.

Finally, differences were found between Engineering micro-domains. Electrical engineering shows the strongest associations of originality, feasibility and effectiveness with creativity, followed by mechanical engineering, with civil engineering and industrial engineering somewhat weaker. However, all differences that are statistically significant are small in magnitude.

Two features of these results stand out in comparison to the results for Person and Process. First, unlike Person and Process, differences that were manifest at the level of GTA did not disappear the deeper the analysis proceeded into the hierarchy. Second, the differences detected both broadened as the analysis drove deeper into the hierarchy, and in some cases, enlarged. In plain language, a small difference in the association of originality with creativity at the level of GTA grew into small associations of originality, feasibility and effectiveness at the level of domains, and indeed grew into slightly larger differences across all three factors at the level of micro-domains. Differences in openness and CSE (Person) and divergent thinking (Process) started small and stayed small, or vanished, whereas differences in the association of Product qualities with creativity started small but expanded slightly in both scope and magnitude.

5. Limitations, conclusions and future research

Several limitations of this study should be noted. First, differences in both gender and age were not considered. As Baer and Kaufman (2008) make clear, there remain many questions about gender differences and creativity. The present study controlled for both age and gender, in order to focus on potential differences by GTA, domain, and micro-domain. Future research, however, should explore the potential impact of these factors, particularly in micro-domains.

Second, while person, process and product factors of the 4P’s framework were investigated, we did not address the press (the environment) in which students operate. The fact that participants were drawn from many different tertiary institutions precluded any meaningful analysis of the impact of their learning environment in this study. It should be noted, however, that the finding – that individuals’ assessments of product creativity are domain specific – likely stems from the contextual (i.e. press) elements associated with each domain (e.g. the different reward systems, demands and constraints present in each domain). The likely impact of press emerges, at the level of micro-domains, as differences in the norms and the culture of each discipline. Future studies therefore should investigate more explicitly possible differences between domains and micro-domains driven by specific environmental or contextual factors unique to those areas of activity. In simple terms, do engineers, for example, learn to think like engineers, in contrast to scientists or mathematicians? Does this then influence how these domains see creativity in products? Cropley and Kaufman (2019) explore this issue in relation to engineers and industrial designers.

A third limitation of this study relates to the variables chosen for analysis. Openness and creative self-efficacy have well-established links to creativity and are a logical starting point for an exploration of domain differences and creativity. With these relationships becoming clearer, an opportunity arises in future research to expand the range of variables examined. To what extent do other aspects of the person, for example persistence, grit or optimism, explain differences by domains? Do factors such as mood or emotional state help to explain the relationship between creativity, GTA, domains and micro-domains?

The results for Person and Process are indicative of factors that are general pre-requisites for creativity. Any individual, to be creative, benefits from high openness, high CSE, and a strong ability to think divergently. Education at all levels must respond accordingly, providing broad support for these elements of creativity. However, the results for Product suggest, albeit only weakly, that individuals’ assessments of product creativity, and the relative importance of originality, feasibility and effectiveness to creativity, are domain specific.
These results support the notion (Plucker & Beghetto, 2004) that creativity, as a manifestation of who we are, and how we think, is general in nature. People who are open, flexible and adept at thinking divergently are best placed to be creative, and education systems at all levels should foster those qualities. Conversely, while all areas of endeavor recognize creativity in outcomes (products) as inseparable from originality and relevance/effectiveness, there are discipline specific differences in exactly how these qualities are valued. It is no surprise that engineers have a more functional (see Cropley & Cropley, 2005) view of product creativity – valuing effectiveness and feasibility in particular – whereas artists place greater emphasis on originality. Creativity in people is broadly domain general, but creativity in products is shaped by the needs, standards and cultures of the disciplines that produce those creative outcomes.

CRediT authorship contribution statement

Kim van Broekhoven: Conceptualization, Methodology, Data curation, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization.

David Cropley: Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Philipp Seegers: Data curation, Resources.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.tsc.2020.100707.

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