Creativity Research Journal

ISSN: 1040-0419 (Print) 1532-6934 (Online) Journal homepage: https://www.tandfonline.com/loi/hcrj20

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Olesya Blazhenkova & Maria Kozhevnikov

To cite this article: Olesya Blazhenkova & Maria Kozhevnikov (2016) Types of Creativity and Visualization in Teams of Different Educational Specialization, Creativity Research Journal, 28:2, 123-135, DOI: 10.1080/10400419.2016.1162638

To link to this article: https://doi.org/10.1080/10400419.2016.1162638

Published online: 09 May 2016.

CREATIVITY RESEARCH JOURNAL, *28*(2), 123–135, 2016

ISSN: 1040-0419 print/1532-6934 online
DOI: 10.1080/10400419.2016.1162638

Routledge
Taylor & Francis Group

Types of Creativity and Visualization in Teams of Different Educational Specialization

Olesya Blazhenkova
Faculty of Arts and Social Sciences, Sabanci University, Istanbul, Turkey

Maria Kozhevnikov
Psychology Department, National University of Singapore, Singapore

This research is the first to examine different types of creativity dimensions in relation to different types of visualization on a team level, by comparing adolescences' teams of different specialization (visual artist, scientists, and humanities) during a complex creative task in an ecologically valid educational setting First, the difference between all teams' creative outputs (drawings) was compared in terms of their visual characteristics and represented content based on parameters derived from the content analysis of visual media. Second, the teams' creative performance was compared using evaluations of experts from different professional domains. Based on the evidence from examination of teams' creative products (final drawings) and their evaluations by professionals, this research suggests that object visualization is related to artistic creativity and spatial visualization is related to scientific creativity on the team-level. Furthermore, the findings provide a clear indication that assessing general creativity independently of the domain, as it has been done so far in most team creativity literature, might be somewhat limited.

The recent emergence of new types of visual media, formed by the interplay of technical invention and artistic expression (as has happened in industrial, graphic, and game design) has led to an increased interest in the creative performance of homogeneous and heterogeneous teams of different specializations (e.g., scientists, engineers, and visual artists). Most of the previous studies that investigated creativity in members of different professions have been conducted primarily at the individual level (see Kozhevnikov & Blazhenkova, 2013; for a review; Kozhevnikov, Kosslyn, & Shepard, 2005), but research on team creativity has lagged behind (see Shalley, Zhou, & Oldman, 2004, for a review). Although there were a number of studies that explored creativity in teams of different specializations (e.g., Shin & Zhou, 2007), as well as creativity in the teams of either artists (e.g., Bilda, Costello, & Amitani, 2006; Hagaman, 1990) or scientists (e.g., Dunbar, 1999; Hara, Solomon, Kim, & Sonnenwald, 2003), they did not explicitly compare the differences in creative products or processes between the teams of artists versus scientists, nor did they specify clear criteria to characterize different types of creativity.

Furthermore, although the majority of social and organizational psychology literature has referred to team creativity as a general concept related to "the production of novel and useful ideas concerning products, services, processes, and procedures by a team of employees working together" (Shin & Zhou, 2007, p. 1715), this definition does not take into account that the criteria for evaluation of creative products and their usefulness have an unambiguous meaning only within a corresponding socio-cultural context, and thus depends on a specific domain (Brannigan, 1981; Warr & O'Neill, 2005). For instance, the criteria used for evaluation of artistic products involve the assessment of aesthetic properties, such as appreciation of beauty and harmony (Amabile, 1979; Barron, Gaines, Lee, & Marlow, 1973). In contrast, judging scientific inventive solutions is based on criteria that emphasize the importance of concept clarity,

Correspondence should be sent to Maria Kozhenikov, National University of Singapore, Department of Psychology, Faculty of Arts and Social Sciences, Block AS4, #02-07, 9 Arts Link, Singapore 117570. E-mail: psymaria@nus.edu.sg

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consensus on the meanings of the mathematical and logical elements, as well as the fit to the current system of the existing scientific knowledge (Leikin, 2009; Simonton, 1988; Stumpf, 1995). Indeed, literature on interdisciplinary collaboration has portrayed members of different specializations approaching creative problems in a conflicting and incompatible manner (Lindauer, 1998; Snow, 1964). Snow (1964) contrasted artists and scientists as standing at the two opposite poles and not being able to find common ground for understanding, although other researchers argued that artists and scientists share a lot of similarities, and that creative individuals are rather polymathic (Root-Bernstein & Root-Bernstein, 2004; Root-Bernstein, Root-Bernstein, & Garnier, 1995).

Nevertheless, the most accepted way of assessing team creativity in social and organizational psychology so far has been based on self-ratings of such general statements as "I have confidence in my ability to solve problems creatively" (Richter, Hirst, van Knippenberg, & Baer, 2012) or supervisors' ratings on such general aspects of team creativity as novelty, significance, and usefulness of the ideas (Shin & Zhou, 2007).

Until recently, the domain-general view of creativity has been quite widespread, assuming that a single creative ability underlies all types of creativity and generalizes to most domains (Plucker, 1998, 2005; Plucker & Zabelina, 2009). In contrast, domain-specific view of creativity suggests that individuals should not be treated as generally creative, but rather as creative in specific domains. Thus, achievement in one creative area such as painting or scientific discovery does not necessarily imply creative excellence in all domains (Ward, Smith, & Finke, 1999) This approach has been heavily influenced by Gardner's (1983) multiple-intelligence theory and his proposal that, similar to intelligence, creativity should be considered as multidimensional (Gardner, 1988). Currently, there is growing evidence supporting the existence of domain-specific creativity, such as scientific, artistic, and verbal creativity at the individual level (Baer, 1998; Carson, Peterson, & Higgins, 2005; Kozhevnikov, Kozhevnikov, Chen, & Blazhenkova, 2013). Kozhevnikov et al. (2013) demonstrated that these different types of visual creativity (scientific or artistic) are related to different types of visual imagery skills, object or spatial visualization respectively. *Object visualization* refers to visualization of visual appearances of individual objects or scenes in terms of their shape, colour, texture, and other visual properties; *spatial visualization* refers to the understanding of spatial relations between the objects and spatial transformations (Farah, Hammond, Levine, & Calvanio, 1988; Kozhevnikov, Blazhenkova, & Becker, 2010; Kozhevnikov et al., 2005). Recent empirical evidence suggests that object visualization contributes to creative performance in art, and spatial visualization ability is largely related to creative performance in science and engineering domains (Kozhevnikov et al., 2013), while these two types of creativity, artistic and scientific, are relatively independent.

Despite the advances in the understanding of domain specificity of creativity at the level of individual differences, there is a clear need for greater attention toward understanding team creativity and redefining more clearly the criteria of team creativity in relation to corresponding domains. The main goal of this research was to investigate creative products and processes in teams of different specializations (i.e., visual artists, scientists, humanities). In particular, the aim was to examine whether domain-specific creativity (artistic and scientific) could be identified at the team level, as well as to investigate the relationship between different types of domain-specific creativity and different types of visualization (object and spatial). The second goal was to investigate creative performance (in terms of creative products and related visualization) in teams of mixed (heterogeneous) specializations in comparisons with creative performance in teams of homogenous specialization.

Although previous studies have provided a thorough and controlled examination of different factors involved in team performance (Banks & Millward, 2000; Cannon-Bowers, Salas, & Converse, 1993; Egan, 2005; Klimoski & Mohamed, 1994; Kraiger & Wenzel, 1997; Milliken & Martins, 1996; Thomas-Hunt, Ogden, & Neale, 2003; Urban, Weaver, Bowers, & Rhodenizer, 1996; Woolley et al., 2007), they did not explicitly compare creative processes in homogeneous and heterogeneous teams composed of individuals with different profiles of visualization abilities and styles (i.e., artists and scientists), nor did they focus on visualization (i.e., visual characteristics of creative products and processes). Furthermore, most of the previous studies were either based on self- or supervisors' ratings of team creativity (Shin & Zhou, 2007) or conducted in laboratory conditions (Bell, 2007), where usually two-person teams were engaged in a relatively simple task (e.g., navigation through a maze and identifying gribble objects, in Woolley et al., 2007; or flight combat simulation, in Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000), which hardly could be generalized to real-life creative tasks, in which visual art, design, science, and engineering professional teams are engaged. In contrast, in this research, the particular interest was in comparing teams' performance on a creative and ecologically valid task, which would present a comparable level of challenge to each team and could be performed in a natural setting.

The collaborative task given to the teams in our study was to draw an "unknown planet;" which could be considered a creative task in the sense that it is open-ended and it allows a variety of approaches in creating the final product. The task was particularly relevant for assessing different dimensions of creativity (e.g., artistic and scientific), because it encourages the use of representations from different domains (e.g., science, visual art, humanities). Participants were heterogeneous and homogenous teams of gifted adolescents who specialized in visual arts, science, or humanities. Humanities teams were included to serve as a control group, because individuals specializing in humanities tend to rely primarily on verbal, rather than object or spatial visual, processing (Blazhenkova & Kozhevnikov, 2009, 2010; Wai, Lubinski, & Benbow, 2009). The adolescent sample was chosen for the purposes of this study because (a) it allowed us to match the requirements of the *drawing of the unknown planet* task with the participants' level of expertise, by presenting a comparable level of challenge to the teams of different specializations (e.g., aesthetic challenge for the adolescents of artistic specializations, knowledge-based challenge for the adolescents of scientific specializations, and story-development challenge for the adolescents of humanities specializations) and (b) the drawing task was an ecologically valid task for this participant pool; it was performed by adolescents in their natural school settings, and the teams' composition (heterogeneous and homogeneous) was based on the actual composition of the classes in the selected schools.

Different methods were integrated to investigate team creativity and visualization. First, differences between all teams' creative outputs (drawings) were compared in terms of their visual characteristics and represented content based on parameters derived from the content analysis of visual media (Aigrain, Zhang, & Petkovic, 1996). Second, teams' creative performance were compared using evaluations of experts from different professional domains.

METHOD

Participants

The study was conducted in Russia (Moscow) because it has specialized schools for gifted adolescents, that use specially designed advanced curricula, concentrating on a specific discipline such as visual art, science, or humanities. The core courses related to the major specialization in these schools are usually taught by professionals in this field and university level faculty. The admission system in the schools for the gifted children in Russia is based on the results of competitive exams and contests or portfolio submissions evaluated by experts in a specific area of specialization.

Eighty-two adolescents (30 boys, 52 girls; 11−17 years old; *M* age = 15.01) were recruited from the specialized schools.[1] On the basis of their school specialization, participants were divided into the following homogeneous specialization teams: visual art, science, and humanities (4 teams of each specialization, with 6−8 participants in each team; see Table 1 for more details).

TABLE 1
Descriptive characteristics of participants within each team

Groups	#	*Males*	*Females*	M *age*	*School specialization*
Visual art	1	1	6	15.86	visual art school
	2	0	7	14.43	visual art school
	3	1	6	14.00	visual art school
	4	0	7	16.29	visual art school
Science	5	6	2	14.75	science camp (physics)
	6	3	3	12.83	science camp (bio & physics)
	7	4	2	13.50	science camp (biology)
	8	4	4	15.50	bio-mathematical school
Humanities	9	1	5	14.67	science camp, humanities section
	10	1	6	16.00	humanities school
	11	4	2	16.17	humanities school
	12	5	2	15.71	humanities school
Mixed	13	4	3	13.14	multidisciplinary school
	14	4	2	13.83	multidisciplinary school
	15	3	3	14.67	multidisciplinary school
	16	3	4	13.57	multidisciplinary school

In addition, 26 participants (12 girls; 12−17 years old; *M* age = 13.77) were recruited from a multidisciplinary school ("League of schools," Moscow) for gifted students. In contrast to schools specializing in one particular discipline, multidisciplinary school admission is based on identifying talents in a variety of different areas, and it offers a variety of advanced curricula in a number of different disciplines (e.g., visual arts, science, or humanities). The individual curriculum is built on the particular strengths of each student giving the student the opportunity to advance within his or her particular area of specialization. The students recruited from the multidisciplinary schools composed four heterogeneous (mixed) teams.[2] The multidisciplinary school provided a unique opportunity to compose heterogeneous teams by bringing together students from different specializations to participate in the study. All the students in each team, including those from the multidisciplinary school, knew each other prior to the study. The assignment to specific teams within all specializations was based on the students' convenience and time availability (to not interfere with school schedules).

Procedure and Materials

The study was conducted in the students' typical school environment: in classrooms either during regular school hours or as a part of school extracurricular activities. Each team was given a large piece of poster board

[1] Most children from multidisciplinary schools focused on one particular specialization. In Group 13, there were 6 students with specialization in science and 1 student with specialization in visual art. In Group 14, there were 4 students with specialization s in science and 2 students with specialization in humanities. In Group 15, there were 3 students with specialization in science, 2 students with specialization in humanities, and 1 student with specialization in visual art. In Group 16, there were 2 students with specialization in science, 2 students with specialization in visual art, 2 with specialization in humanities, and 1 student with mixed specialization in science and art.

[2] Forty-five min is the typical length of a lesson in Russian schools.

(33.11in. × 23.39 in.) and various drawing materials: markers, color pens, crayons, pastels, water colors, gouache, and charcoals. The poster board was placed on the table, and the participants were encouraged to move freely around the table while drawing. Prior to drawing, all participants received the following verbal instructions:

> Dear children, your task is to imagine and to draw an unknown planet. You have to work together as a team. You can move freely around the table and use any materials and any space on the paper, but please let others do so, too. Please feel free to communicate with each other. Please try to complete your work within 30–40 minutes.

The overall time allotted to the task was 45 min.[2] Participants were allowed to finish earlier if they all agreed that their work was completed.

After completion of the task, brief semistructured interviews were conducted with each participant individually about their experiences working on the project. All the drawing sessions and interviews were videotaped and transcribed.

RESULTS

Content Analysis of Teams' Drawings

The final drawings of all the teams are shown in Figure 1. During the visual content analysis, four independent judges analyzed and compared the content of the drawings across several categories while referring both to students' drawings, as well as to their interview reports on the meaning of their drawings. The categories of analysis were adopted from the content analysis of visual media (Aigrain et al., 1996), which defines several types of visual similarity (e.g., shape, spatial segmentation, color, texture, and object presence) used for comparing image content. The categories were modified and expanded for the purpose of this study, and were defined as follows: (a) shape, (b) perspective and

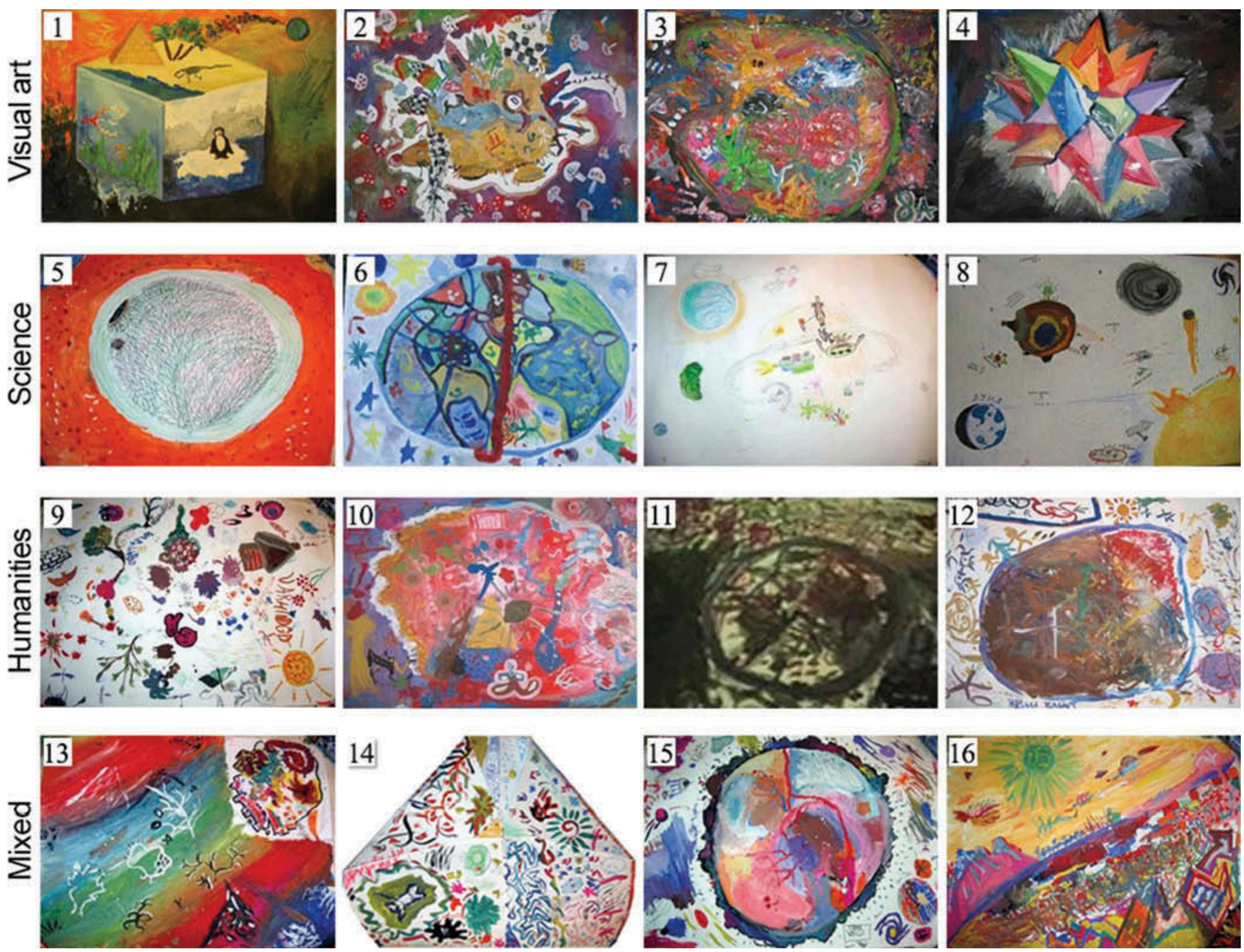

FIGURE 1 Teams' final drawings.

composition, (c) use of colors and materials, (d) use of verbal labels, and (e) represented meaning of the drawings. The four judges, upon agreement, described the differences and unique characteristics of the drawings across these categories.

Drawings of "Visual Art" Teams

Shape. All visual artists drew nonspherical planets in shapes of different complex objects (cubical in Team 1, in a shape of a hedgehog in Team 2, in a shape of an artistic palette in Team 3, and shaped as a many-sided crystal in Team 4). Two of the drawings (Team 1 & Team 4) rendered three-dimensional shapes, which tended to have depth and distance cues.

Perspective and Composition. All drawings represented a planet as one large central object. Visual artists did not depict realistic spatial compositions and placement of objects, and did not preserve objects' relative sizes. For example, scenes on different sides of the cube in the drawing of Team 1 were drawn at different scales (e.g. sea grass was as high as trees), mushrooms in the drawing of Team 2 had the same sizes as houses.

Use of Colors and Materials. Visual artists had extensive blending of colors and rich palettes. They fully filled in backgrounds; most drawings did not have any unpainted white or monochromatic space. All teams painted primarily with brushes and color paints.

Use of Verbal Labels. Visual artists' drawings did not use any verbal labels on their drawings.

Represented Meaning. Visual artists' drawings represented planets in nonfigurative way. That is, they depicted concrete common objects and living beings in unrealistic/fantastic context, and used these objects to symbolize planets or other cosmic bodies. For example, Team 2 drew the planet-hedgehog with houses on its surface, which symbolized the planet, and mushrooms surrounding it, representing stars. Team 3 drew an artistic palette, which also referred to a planet, and Team 4 drew a crystal, symbolizing a star and a planet.

During the follow-up interviews about the represented meaning, visual artists generally expressed consensus with regard to the content of the drawing, although, sometimes there was variability in interpretations ("I drew stars here, but Nadya painted them over. … Maybe she thought they were drops."). Interestingly, visual artists were often inferring the meaning from the drawing itself rather than from verbal communications between each other ("Sometimes it was unclear what others were drawing during the process. … However, it became clear when it was drawn.").

Drawings of Science Teams

Shape. Unlike visual artists' drawings, all scientists' drawings represented conventional spherical/circular shapes of the planets. Interestingly, all science teams initially proposed drawing nonspherical shapes of the planets as "more original" alternatives; however, in all of the teams these proposals were rejected for the same reason of implausibility ("Let's make it non-round-shaped. — No, it will not be interesting. — Why not? Why should we follow the rules of astronomy? This is an UNKNOWN planet. — So what? It is KNOWN that it is impossible to make a planet like this.").

Perspective and Composition. Scientists drew planets from conventional perspectives, similarly to how planets are represented in textbooks. The unknown planets were surrounded by a variety of typical cosmic objects (stars, satellites, spaceships etc.). Teams 7 and 8 represented complex spatially arranged scenes including several large cosmic objects (e.g., other planets, sun, moon, Earth), and two other teams represented a single large planet in the center of the composition. Unlike visual artists, scientists paid special attention to representing realistic spatial arrangement of planets and other cosmic bodies, as well as to preserving their correct relative sizes.

Use of Colors and Materials. In contrast to visual artists, scientists' drawings had limited palettes, used little or no blending of colors, were created using mixed media (paints, pencils and markers), and all had monochromatic (e.g., Teams 5 & 6 used one plain dominant color for background) or white backgrounds (Teams 7 & 8). Interestingly, many participants explicitly admitted that they preferred not to draw with colors and expressed preferences for drawing with pencils and crayons because they preferred clear colors or black-and-white sketching ("Paints just make mud and mess."). However, some expressed that they felt that the task demanded they draw with paints, because they were provided along with the instructions. The selection of colors was either based on conventional knowledge about typical colors associated with certain objects or environments ("Sun should be yellow."), or it was arbitrary, for the sake of diversity, but never motivated by aesthetics ("Lets fill these spots with colors … yellow and green. — I don't like yellow and green colors… — What do you mean 'I don't like'? It can be any color.").

Use of Verbal Labels. Only one drawing by scientists (Team 8, which included mostly biologists) used verbal labels that were placed next to objects for a reference, e.g., "moon" or "Little Prince".

Represented Meaning. All scientists' drawings resembled typical representations of planets and objects commonly associated with cosmos, such as craters, satellites, sun, rings around planets, and continents on the surface of the planet. During their conversations about planets' content, scientists often referenced conventional knowledge and textbooks. For example, Team 5 drew a planet with cracks on the surface, which attempted to follow realistic, conventional representations of a planet. Three of four teams (6, 7, & 8) represented a planet resembling Earth. There was one exception when scientists included fantastic elements, referring to the popular science fiction fable *The Little Prince* by Saint-Exupery (de Saint-Exupery, 1943) (referred to by Teams 7 and 8, which included mostly biologists). Interestingly, the science teams that included biologists created drawings that represented living things such as people and plants; the other two science teams (mostly including physicists) drew planets with no obvious signs of life.

According to their feedback after the completion of work, scientists were clear and unambiguous about the meaning of their drawings. Within each team of scientists, there was a pronounced consistency in interpretations, and a great deal of shared understanding of drawn representations. Notably, science teams displayed a marked desire for consistency. For example, when one student was drawing cracks on the planet's surface while others looked on, other participants realized that they had a time limit and suggested that he draw with both hands (and later suggested helping him), however, the team expressed a concern that the style and width of the drawn patterns would be inconsistent.

Drawings of Humanities Teams

Shape. All humanities teams drew assortments of different objects with various shapes and sizes, sometimes even without outlining the overall shape of the planet (Teams 9 & 11), or they drew roughly round planets (Teams 10 & 12). Team 11 transformed their original painting from a pattern of objects to a round planet.

Perspective and Composition. The drawings contained miscellaneous objects, oriented differently from each other, without elaborated and consistent perspective. Often, the composition was generated rather spontaneously, based on the convenience of participants' locations around the table. The objects' arrangement and their relative sizes were not realistic, especially in the context of a planet (e.g., Team 9 placed the sun on the surface of the planet among the other objects). Some objects, which in reality should be positioned on the surface of the planet, were positioned in outer space (for example, Team 10 placed people playing volleyball outside the planet).

Use of Colors and Materials. Humanities teams used mixed media (crayons, paints, markers). Their representations had little artistic blending. Similar to the scientists, they had monochromatic or uncolored background (Teams 9 & 12). However, unlike scientists, they drew muddled color patterns (Teams 10, 11 & 12).

Use of Verbal Labels. Unlike visual artists and scientists who tended not to use words in their drawings, three of four humanities teams used words (Team 11 used words only in the original version, and later painted them over). Humanities students suggested drawing verbal labels and arrows to clarify the drawing's meaning ("No one would ever say that this is a planet. — Let's write that it is a planet and draw arrows to make people understand."). This may indicate that they attempted to compensate for the lack of visualization and drawing ability by using verbal labels.

Represented Meanings. Humanities teams' drawings did not portray physically plausible representations of the planets. Instead, they represented assortments of common objects, usually not related to each other and to a planet context. For example, Team 11 originally drew a mixture of objects that were not clearly related to each other (which looked very similar to Team 9's drawing); but in the final drawing, this team painted over it with muddled colors. Teams 10 and 12 reported that they drew color patterns to represent "abstractions" in the sense of being difficult to understand, rather than conveying any specific meaning.

In their interviews, as well as during the process of drawing, participants admitted that they failed to create coherent drawings with consistent and well-developed concepts behind them. They reported a great deal of unpredictability in the process of their drawing, such as how originally planned objects turned out to be different from what was intended, mostly due to lack of drawing ability ("I painted this house that was originally planned as an anthill, however, it happened to be more like a house than an anthill;" "Since I have a very bad drawing, I decided to draw a bunch of spots, and then I decided that this would be a flower, but it got too big for the flower. … Even I drew this one flower, I'm drawn to abstraction, because I do not know how else to draw, and indeed I don't even know how to draw abstraction."). During the drawing, participants were aware of the difficulties with forming meaningful drawings, and they were self-ironical about it ("See … we have not developed any concept." — "Well, but how can it be without a concept?" — "If you want to, I'll write the word here—'concept' so it will be it.").

Humanities teams exhibited a low awareness about what members of their team had drawn, and demonstrated a great disparity in interpretations (except for recognizing common objects such as a guitar) and a lack of a common shared idea ["I don't know why girls drew fruits here. … Maybe they like fruits, but why here?" "I don't know why they drew noughts and crosses … maybe it was a joke?" "I cannot understand, what was meant here. Was it something specific or was it just the paint spread out, as would be the case with me. Here it could be a tree, or at least a bouquet of flowers. Or it can be a mood, or something like some small world, or maybe just an abstraction."). For example, in Team 11, there was a pronounced variability in interpretations of the final painting-over, e.g., a planet after an explosion, a reflection of emotion (from funny to very dark and bad), a representation of an internal world of a person, or just a nonsense mix of colors etc.

Drawings of Mixed Teams

Shape. Three of the four mixed teams drew complex and mostly nonconventional planet shapes (only Team 15 represented a nearly round-shaped planet). For instance, Team 14 represented the planet in the shape of a spaceship (the paper is actually folded similar to paper airplane style to achieve 3D shape and both sides of the paper were completely filled with drawings before folding). Teams 13 and 15 represented irregular, jagged edges of the planets and Team 16 drew cubism-style shapes of the underground composites of the planet, as well as some shapes of realistic objects such as mountains, rocks, machineries and living things.

Perspective and Composition. Mixed teams produced pictures with unusual compositions. For example, Team 13 combined the view of the planet from both close-up and remote perspectives. Team 14 used both sides of the paper and folded it into a 3D airplane shape. Team 16 represented the planet with both underground and above the ground views. Teams 13 and 16 represented their planets from close-up views and drew their planets' surfaces from a diagonal orientation. Team 14 filled the entire paper surface on both sides before folding it into a 3D shape. Only Team 15 represented the planet from a remote perspective.

Use of Colors and Materials. Mixed teams' preferences in using colors and materials depended on the team composition. For example, Team 14, which included participants with science and humanities specializations, created a drawing that had a limited use of colors and a white monochromatic background, similar to homogeneous science or humanities teams. It is interesting that other teams, which included at least one or two artists, employed a variety of different colors, complex color blending, and unusual color choices, similar to the homogeneous teams of visual artists. For example, Team 16 used paints in an unusual way (e.g. yellow for sky, green for sun), Team 13 filled the background using a color gradient, and Team 15 extensively mixed colors and created different shades.

Use of Verbal Labels. Only Team 14 (which consisted of scientists and humanities) used words in their drawing.

Represented Meanings. All mixed teams invented complex, well-developed stories behind their pictures, which integrated realistic, fantastic, and abstract artistic elements. For example, Team 14 represented the mechanical planet—a spaceship that was originally built by humans, which contained its own God, machinery, and life.

Similar to visual artists, they represented fantastical creatures, as well as common objects in unrealistic contexts. For example, Team 16 represented fantastic elements (green sun, flying dragon) and various abstract shapes, and Team 15 drew a planet of cats, which mixed both realistic and fantastic elements. On the other hand, similar to scientists, they represented comets, satellites, stars, and other cosmic bodies (e.g., Teams 15 & 16 drew planets surrounded by satellites, asteroids, comets, and other planets and stars). Team 16 represented realistic elements (plants, animals, mountains). Similar to humanities teams, they sometimes drew assortments of objects and unidentifiable splotches of color and patterns of lines (Teams 16, 13, & 14).

Mixed teams demonstrated a coherent and shared overall understanding of the drawn concept, but some degree of variability in their interpretations, most likely (as was evident from their interviews) because individuals in mixed teams tended to focus on different aspects of the drawing. For example, participants with visual art specializations within the mixed teams were more concerned with the choice of colors, aesthetics and surface features; scientists in the mixed teams were more concerned with their planets' function and the rules of its existence. In their interpretations of the final drawings, participants were describing representations relevant to their concerns. However, they were rather tolerant of differences in interpretations outside their focus areas ("Everything is clear for me, however, I don't understand why Sasha drew these stripes and what it mean … but I don't mind … if it means something for her.").

The summarized descriptions of teams' differences according to the defined categories are presented in Table 2.

Discussion

These results revealed the systematic differences between specialization teams' drawings across all categories of visual content analyses: shape, perspective and composition, use of colors and materials, use of verbal labels, and represented meanings. In particular, the teams of *visual artists* tended to create drawings rich in object properties (using complex color palette, color blending and shades, pictorial detail, complex texture) and did not represent realistic spatial relationships. In contrast, the drawings of *scientists*' teams had consistent and elaborated spatial compositions, reflecting realistic spatial relationships, but less developed object properties (e.g., a lack of texture details and color blending), and less use of colors. This comparison suggests that the teams of visual artists, indeed, rely primarily on object visualization during the drawing process and the teams of scientists rely largely on spatial visualization.

Humanities teams reported a lack of imagery ("I don't know how to draw, I cannot even imagine things.") and their drawings indeed were poor in both object characteristics (e.g.,

TABLE 2
Summary of differences between different teams' drawings

Visual Art	*Science*	*Humanities*	*Mixed*
Shape			
All groups drew non-spherical planets in shapes of different objects.	All groups drew spherical/circular conventional planets.	Half drew assortments of objects without outlining the shape of the planet; half drew round planets.	Majority (¾) drew non-conventional shapes; only ¼ drew round-shaped planet.
Perspective and composition			
All groups represented planet as one large central object.	All groups drew the planets (one or several) in the Universe surrounded by other cosmic objects, as in the conventional textbook perspective.	Most of drawings did not have a consistent perspective, and the objects were oriented differently from one another.	Majority (¾) drew complex perspectives and orientations, used 3D folding, cross-sections, and combining perspectives.
Use of colors and materials			
All groups painted primarily with paints. Rich palettes, extensive blending colors, fully filled in backgrounds.	Used mixed media, limited palettes, no blending of colors, all drawn on a monochromatic or white background.	Mixed media, limited palette and little blending. Monochromatic, muddled color patterned, or uncolored background.	Mixed media, but primarily paints, broad palettes, unusual color choices, and extensive blending, ¾ filled backgrounds.
Use of verbal labels			
Drawings did not have any text.	Only ¼ used verbal labels.	The majority (¾) used words.	Only ¼ used words.
Represented meaning			
The drawings were non-literal representations of planets, though some contained realistic elements used in non-conventional contexts.	Less or more realistic, literal representations of planets' contents and their surrounding objects, consistent with conventional knowledge, textbooks or fiction.	Mostly realistic objects, but the arrangement was not realistic, and not related to planet context. Some abstractions, but without assigning complex symbolic meanings.	Objects ranging from realistic objects, to fantastical creatures, to unidentifiable splotches of color. Most drawings had complex, well-developed stories behind.

limited palette, muddled color patterns, little detail in objects' appearances), as well as spatial features (inconsistent and unrealistic spatial composition). In comparison with other teams, humanities teams tended to use more verbal labels to compensate the lack of clarity in their drawings.

Mixed teams shared similarities with all types of teams. On one hand, similar to the artists' drawings, mixed teams' drawings represented developed object characteristics (e.g., elaborated pictorial appearances, broad palettes, and extensive blending), and on the other hand, similar to scientists' drawings, their drawings represented advanced spatial composition. Thus, mixed teams were capable of uniquely integrating both object and spatial visualizations in their drawings.

Overall, the results of the content analysis show that depending on a team specialization, its creative product is likely to rely on very particular visualization aspects (object visualization for a team of artists, spatial visualization for a team of scientists, both object and spatial visualization for a mixed team, and not clear preference to either object or spatial visualization for a team of humanities). Furthermore, according to the teams' reports on the represented meaning of their drawings, the visual art, mixed, and science teams used visualization for different purposes. Visual artists and mixed teams primarily used object visualization as a means to express their own individual imagery, subjective visual experiences and fantasies, whereas scientists used their spatial visualization as a means to communicate the ideas in a conventional way and to facilitate a shared unambiguous understanding.

Estimation of the Drawings by Experts from Visual Art and Science

Expert evaluations have been often used to examine creative products in the literature (Amabile, 1979; Baer & McKool, 2009). The goal of this study was to investigate different criteria used by experts from different domains to evaluate the drawings of the teams of different specialization. Members of different professions from Russia and the United States of America, who were experts in their field, and had a college degree and experience of more than several years in their field, were personally invited by e-mail to participate in an online survey and to evaluate adolescents' drawings. Overall, 12 professional visual artists (e.g., specializing in painting, graphic design, and fine arts), 15 professional scientists (e.g., specialising in math, physics, and computer science), and 12 humanities professionals (e.g., specializing in history, journalism, and philosophy) completed the evaluation.

Photographs of all the drawings along with evaluation questions were posted in an online survey. Expert professionals were blind to the goals of the study and were not aware of participants' specializations. The general instruction was the following: "Sixteen teams of adolescents were given a task to draw a picture of an unknown planet. Please, look at the pictures that they drew. You will be asked to evaluate them." Professionals were asked to estimate adolescents' drawings using a 1–5 scale on the artistic quality ("Please rate the artistic quality of the picture above.") and concept clarity ("How useful and clear is the concept behind the picture?"). The criteria of artistic quality and concept

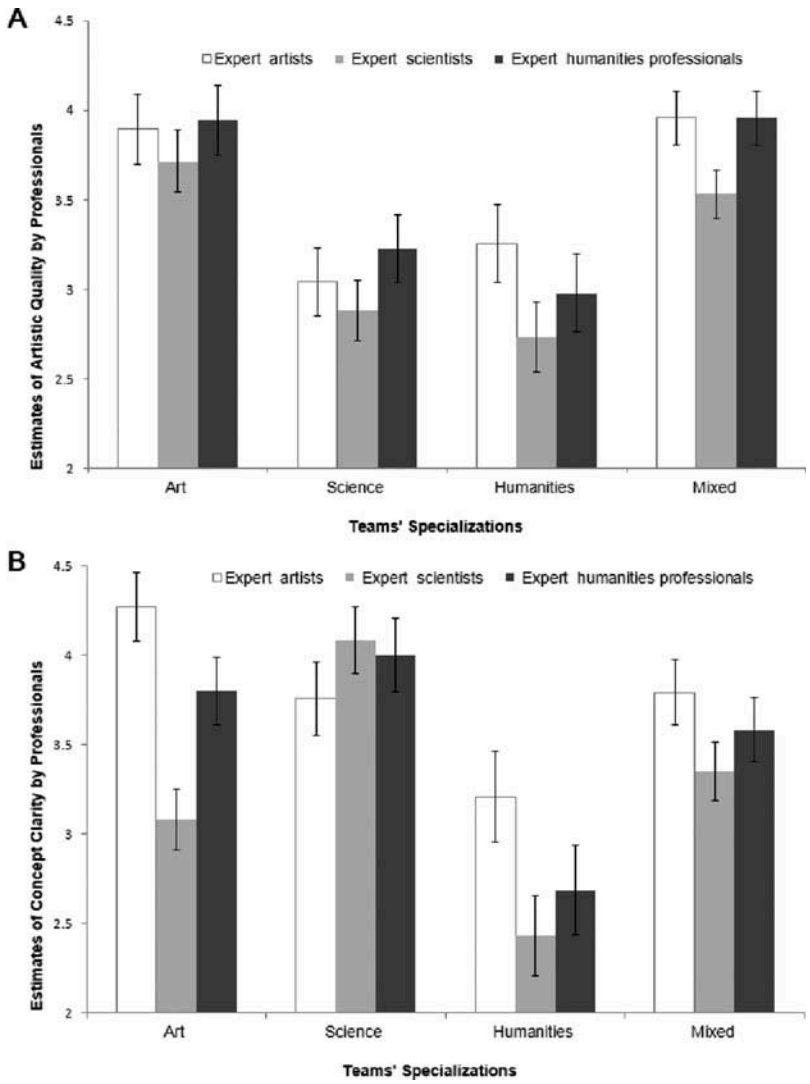

FIGURE 2 Visual art, science and humanities professionals' estimations of adolescents' drawings on Artistic Quality (A) and Concept Clarity (B).

clarity were chosen on the basis of the notion of domain-specific artistic versus scientific creativity: Although artistic quality is recognized as a main aspect of a creative product in the domain of visual art (Amabile, 1979), concept clarity is one of the important characteristics of a creative product in scientific domains (Leikin, 2009).

Comparison of Experts' Estimates

The differences in estimations of artistic quality and concept clarity between the expert visual art, science, and humanities professionals are represented in Figure 2A and 2B, respectively. The data were analyzed using a 4 × 3 mixed-model ANOVA with team specialization (visual art, science, humanities and mixed teams) as a within-subjects variable and experts' specialization (visual art, science and humanities professionals) as a between-subjects variable. There was a significant main effect of team specialization on estimation of artistic quality: $F(3, 34) = 45.308$, $p < .001$, $\eta_p^2 = .800$). Pairwise comparisons (Tukey) showed that visual art ($M = 3.85$; $SD = .11$) and mixed teams ($M = 3.82$; $SD = .08$) were estimated significantly higher in artistic quality (all $ps<0.001$) than science ($M = 3.05$; $SD = .11$) and humanities teams ($M = 2.99$; $SD = .12$). There were no significant differences between mixed and visual art teams ($p = .74$), as well as between science and humanities teams ($p = .59$). The between-subject main effect was not significant, indicating that there were no differences in estimations of artistic quality between members of different professions. None of the interactions were significant.

Next, with regard to concept clarity, the analysis revealed significant main effect of team specialization: $F(3, 34) = 24.11$, $p < .001$, $\eta_p^2 = .680$. Pairwise comparisons (Tukey) showed that science teams' drawings were estimated significantly higher on concept clarity ($M = 3.94$; $SD = .12$) than drawings of humanities teams ($M = 2.78$;

$SD = .14$) ($p < .001$) or mixed teams ($M = 3.58$; $SD = .10$; $p = .004$), and tended to be estimated higher than drawings of visual art teams ($M = 3.72$; $SD = .11$; $p = .09$). Humanities teams were estimated as the lowest among all teams (all $ps<.001$). There were no differences in estimations of visual art and mixed teams ($p = .20$). The effect of experts' specialization was marginally significant, indicating that there was a difference in estimations of concept clarity between professionals of different specializations, $F(2, 36) = 3.10$, $p = .057$, $\eta_p^2 = .147$. Pairwise comparisons (Tukey) showed that professional visual artists in their estimates of concept clarity were higher than professional scientists ($p = .018$), indicating that scientists might be more critical in their estimation on this parameter. There was also a significant interaction between experts' specialization and team specialization, $F(6, 70) = 3.07$, $p = .01$, $\eta_p^2 = .209$. Follow-up ANOVAs revealed that science professionals tended to estimate scientists' adolescents' drawings as more conceptually clear than visual artists' drawings ($p = .001$), and vice versa for visual art professionals ($p < .05$).

Overall, according to professionals' estimates, visual art and mixed teams' drawings were estimated as the highest in artistic quality, whereas science teams were the highest in concept clarity. Interestingly, on concept clarity, mixed teams were estimated by professionals as high as the teams of visual artists but not as high as teams of scientists. humanities drawings were consistently evaluated as the lowest on both artistic quality and concept clarity.

Discussion

The results of professional evaluations of the students' drawings suggest different criteria for evaluating a creative product by artists versus scientists. Visual art and mixed teams' drawings were estimated as the highest in artistic quality, science teams were estimated as the highest in concept clarity, whereas humanities drawings were evaluated as the lowest on both artistic quality and concept clarity. The criterion of concept clarity, and specifically, the accuracy of spatial relations, was the most important for professional scientists. Indeed, they were more strict and discriminative in their estimates of concept clarity than the experts in visual art. In contrast, artistic quality criterion was not important for scientists who expressed concerns that they were not competent enough to evaluate it ("Questions about artistic merit drove me to a full stupor;" personal communications). Visual artists, however, were mostly concerned with artistic quality aspects, often related to object visualization (color palette), while accepting an ambiguity in concept interpretations, and leaving it for every ones' personal understanding.

Mixed teams were estimated among the highest (together with visual artists) on artistic quality, but not on concept clarity (they were significantly lower than scientists) suggesting that their imagery was more directed toward an artistic expression of their mental experiences, similar to visual artists, rather than toward conveying a clear scientific representation. Possibly, mixed teams were restricted by a contradiction between generating clear unambiguous representation and creating artistic representations rich in visual fantasy, and chose the latter at the expense of unambiguity. These results were surprising, taking into account that most mixed teams had only 1–2 visual artists.

Overall the results suggest that it might be somewhat limited to refer to team creativity as a general concept related to "the production of novel and useful ideas" without taking into account that the criteria for expert evaluation of creative products depend largely on the domain. Furthermore, the results also suggest that artistic criteria for evaluation of creative products address primarily aesthetic (beauty) and object visualization aspects of the product (color or pictorial detail); scientific criteria address the products' clarity of the idea and spatial visualization aspects (accuracy of spatial composition and representation of realistic spatial relationships).

GENERAL DISCUSSION

This research is the first to examine different types of creativity dimensions in relation to different types or visualization on a team level, by comparing adolescences' teams of different specializations during a complex creative task in an ecologically valid educational setting. Furthermore, it is the first research that examined team creative products, using distinct criteria to assess both artistic and scientific creativity (aesthetic vs. conceptual characteristics).

One of the limitations of this research is its exploratory nature and case study approach. More studies will be needed on the creativity of interdisciplinary teams to support the findings experimentally. Another limitation of the study is the use of adolescents' sample, which might not be fully generalizable to interdisciplinary teams of professional experts. However, it should be noted that adolescents' visualization abilities are more or less fully developed by age of 10–12 (Blazhenkova, Kozhevnikov, & Becker, 2011), and adolescents' visualization strength (e.g., object or spatial) relates reliably to their educational and future career interests in different specializations (e.g., visual art or sciences) (Kozhevnikov et al., 2010). Thus, the use of adolescents' versus adults' samples was unlikely to significantly affect the findings of this study.

In contrast to previous research that focused primarily on individual-level analysis, this research was the first to demonstrate that individual differences in visualization manifest at the team-level and relate to team creative performance and processes. Based on the evidence from the qualitative examination of groups' creative drawings, a number of important differences in creativity were identified and related visualization between teams of gifted adolescents specializing in visual art, sciences, and humanities, as well as mixed specialization teams. Overall, creativity in visual art teams tended to rely primarily on object visualization, and in science teams on spatial visualization. Humanities teams did not show any clear preference for either object or spatial visualization but rather tended to rely on verbal processing. As for the mixed teams, they were the only teams capable of integrating both object and spatial visualization aspects.

Furthermore, the results suggest that visualization plays a different functional role for teams of different specializations. In particular, visualization played a significant role for creativity of the visual art, science, and mixed teams, as was evident from the richness of visual characteristics in the teams' final drawings. These findings are consistent with previous studies that demonstrated the crucial role of visualization in guiding the creative work of visual artists as well as for science, engineering and technology specialists (Blazhenkova & Kozhevnikov, 2010; Kassels, 1991; Kozhevnikov, Motes, & Hegarty, 2007; Miller, 1996; Pellegrino, Mumaw, & Shute, 1985). Remarkably, although the visual art, mixed, and science teams relied on visualization to guide their creative process, as mentioned, they used it for different purposes. Although visual artists and mixed teams used their imagery experiences as a main source of inspiration for their creative drawings, the teams of scientists use imagery to communicate, as well as to solve problems that involve an unequivocal understanding of spatial, conceptual and functional relationships (see also Gooding, 2004; Rosenberg & Trusheim, 1989).

Importantly, the results of this study, including the content analysis of drawings and experts' ratings, show that such different approaches in using visual imagery are associated with qualitatively different types of creative outputs. First, the main focus in the team of artists was placed on the creative generation of visual appearances and their aesthetic expression, and the team of scientists in their creative work was primarily guided by conceptual clarity and functional relevance. Second, the results of expert's rating of the students' drawings suggest different criteria for evaluating a creative product. The criterion of concept clarity, and specifically, the accuracy of spatial relations, was the most important for professional scientists, while artistic quality and object visualization aspects (color, pictorial details) were the most important for the artists.

Overall, the results are consistent with previous research that related different dimensions of creativity and visualization at an individual's level (Kozhevnikov et al., 2013), this research suggests that object visualization is related to artistic creativity and spatial visualization is related to scientific creativity on the team-level, as well. Furthermore, the findings provide a clear indication that assessing general creativity independently of the domain, as it has been done so far in most team creativity literature, might be somewhat limited.

One second research question was related to the creativity and visualization processes in mixed (heterogeneous) teams in comparison with homogeneous teams. As the results show, visualization strengths of individuals composing a team, shaped the team performance in the direction consistent with the individual strengths (e.g., visual art teams excelled in object visualization, and received high evaluations in estimates of artistic creativity—artistic quality; science teams excelled in spatial visualization, and received high evaluations in estimates of scientific creativity—conceptual clarity). However, this was not the case for the humanities teams, who did not have any particular visualization strengths to build on. As for the mixed teams, they were the only teams who were able to uniquely integrate object and spatial characteristics in their drawings. As was demonstrated by previous research (Kozhevnikov et al., 2010), the integration of object and spatial visualization may be quite challenging at the individual differences level, due to restrictions in an individual's overall visualization resources. Our results suggest that heterogeneous teams composed of members with different visualization profiles are able to overcome this challenge and that individuals' restrictions in visualization abilities may be compensated for by composing heterogeneous teams that work collaboratively on complex visual tasks requiring high levels of both object and spatial processing.

Nevertheless, although the mixed teams shared some similarities across a number of parameters with the teams of scientists and humanists, they appeared to be most similar to the visual arts teams. The mixed teams' drawings received estimations that were as high as the visual arts teams' on artistic quality, but not as high as scientists teams' on concept clarity. This indicates that, similarly to visual artists, mixed team members were more concerned with visual appearance than with functional and conceptual properties. This similarity seems surprising when taking into account that most of the mixed teams had a majority of scientists and only a few visual art members. One of the reasons why this happened in our study could be that all the teams tended to interpret the task of drawing an unknown planet more as an artistic, rather than scientific, challenge. Indeed, even some science team members interpreted the presence of drawing materials and paint as an indication of artistic aspects that were required by the task, and expressed their concerns about it. Similarly, using a task which benefited more from spatial processing, Aggarwal and Woolley (2013) reported that teams of high spatial visualizers were more process-focused (attending to rules), and that the presence of even one strong spatial visualizer helped a team to be process focused. Thus, it is possible that the relative role of visual artists and scientists in various collaborative projects depends on the nature of the task. For example, in more artistic projects (such as film production), visual artists, regardless of their number, might play a major role. However, in more scientific projects (such as illustration of scientific content), scientists might play a leading role.

This study provides valuable findings for cognitive, social psychology, human factors, education, and other applied fields. In response to a growing interest in art-science interdisciplinary collaboration, this research offers new insights on the heterogeneous nature of team creativity, and its relation to different aspects of visualization. It also offers insights about the limitations and possibilities of fruitful collaboration between individuals with diverse specializations.

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