Perceptions of Creativity in Software Engineering Research and Practice

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***Abstract*—Software engineering, especially design and requirements engineering, is intensely creative. However, practitioners and researchers appear to perceive creativity differently, hindering knowledge transfer. To explore and understand these perceptual differences, this paper combines a systematic mapping study of SE research literature with an interview study of practitioners. The subsequent analysis of 84 primary studies and 17 semi-structured interviews reveal some agreement (e.g. creativity is a process that produces novel and useful ideas). However, it also reveals important differences in the way creativity is conceptualized, measured and improved. These differences undermine evidence-based techniques to enhance and measure creativity in SE research and practice.**

Keywords-creativity; interviews; systematic mapping; software engineering

I. INTRODUCTION

Creativity is a central topic of investigation in numerous disciplines including psychology [1], engineering [2], education [3] and management [4]. Broadly speaking, creativity refers to "a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions, making guesses, or formulating hypotheses about the deficiencies: testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results" [5, p. 6]. Moreover, creativity involves generating ideas, which are not only new, novel or original but also useful, feasible or effective [6].

Software design, requirements engineering (RE) and programming are recognized as creative processes [7], [8]. A handful of software engineering (SE) studies seek to understand creativity in SE contexts (e.g. [4], [7], [8]) or examine creativity from an practitioners' perspectives (e.g. [9], [10]). Rather, most SE studies involving creativity rush to prescribe tools or techniques to enhance it (e.g. [11], [12]). While researchers and practitioners in psychology and philosophy have built consensus around the dimensions of creativity in their domains [13], SE researchers and practitioners have not.

Creativity research can be divided into the "Six P's" [14], [13], as follows.

1) creativity's underlying cognitive **process**
2) the **product(s)** of creative work
3) the **person** (or personality) doing the creative work
4) the **place** (context) of the work
5) how to improve creative thinking (**persuasion**)
6) how to improve our creative **potential**

While some SE studies focus on *process* (e.g. [8]) and place (e.g. [15]) Most SE research appears to focus on *product* [16].

Additionally, assessing creativity remains challenging because creativity is multidimensional, subjective, difficult to quantify and not completely understood. Since our shared understanding of creativity guides assessment [1], consensus between researchers and is critical to develop appropriate approaches for assessing creativity. More generally, the role of creativity in SE can be better understood only when the understanding, expectations and the reservations of both the communities are accounted for.

This argument motivates the following research question:

> ***Research Question:*** *How is creativity perceived both in the software engineering research literature and by software engineering practitioners?*

To investigate this question, we adopt a multimethodological approach [17] comprising a systematic mapping study, followed by a constructivist interview study. By comparing and contrasting researchers' and practitioners views we can better understand impediments to knowledge transfer and practice adoption.

We next describe the research approach (Section II) and results (Sections III and IV). Section V discusses the implications and limitations of our study. Section VI reviews the existing literature on creativity in general and in SE. Section VII concludes the paper with a summary of its findings and recommendation for future research.

II. RESEARCH METHODOLOGY

This paper employs a systematic mapping study to explore how the SE research literature characterizes creativity. Meanwhile, it adopts a cross-sectional interview study to investigate practitioners' perspectives on creativity. It then attempts data triangulation—that is, comparing and contrasting the dimensions of creativity that emerge from the mapping and qualitative analysis.

To this end, we found it helpful to divide our research question into three sub-questions:

RQ1: How is creativity conceptualized in SE?
RQ2: What factors influence creativity in SE?
RQ3: How is creativity measured in SE?

A. Systematic Mapping Study

Aggregating and categorizing the available research on creativity in SE seemed quite broad, so a systematic mapping study was preferred over a detailed review. This allowed us to categorize the evidence, based on the sub-research questions at a high degree of granularity [18], [19]. We compiled the mapping protocol based on Kitchenham and Charters' guidelines [20].

The mapping protocol consisted of study objectives, research questions, search strategy, inclusion criteria, primary study selection process, and data extraction strategy. It was reviewed iteratively by the first two authors and revised as needed. To keep the search as broad as possible, we searched the digital libraries, using the search string *'creativity' AND 'software engineering'*. The search was conducted on the full-text (not only the meta-data) for publications until November 2015. The search process produced a total of 8,872 entries from Scopus (2,695), IEEE Xplore (3,268), ACM (1,385) and Science Direct (1,524).

The results were exported to Refworks (http://www.refworks.com). Automatic de-duplication in Refworks, followed by manual deduplication by inspection left 7,655 studies. These were subjected to the following inclusion criteria:

1) must be written in English
2) must belong to a journal or any conference or workshop proceedings
3) must be peer-reviewed
4) must be relevant to software engineering
5) creativity must be the central focus of the paper

The first and third author piloted the inclusion criteria on 30 randomly selected articles. A Fleiss Kappa value of 0.7 denoted a medium-high agreement [21]. After resolving the conflicts by mutual agreement, the same authors analyzed 20 further randomly selected papers. When the two assessors agreed on all 20 papers, we judged the inclusion rubric as reliable.

A total of 84 articles were subsequently included[1] and evenly divided between the same authors, who extracted the following data: publication year, definition of creativity, approaches to measure creativity and factors influencing or enhancing creativity. As a reliability check, the first and third author independently cross-checked each other's analyses (extracted data) for any inconsistency and resolved discrepancies by discussion.

B. Interview Study

A semi-structured interview guide was developed following established guidelines [22], [23] to address the three research questions from different directions[2]. We conducted three pilot interviews to validate the guide, resulting in minor updates. We then interviewed a convenience sample of 17 SE practitioners (16 male and 1 female)—see Table I. Five interviews were conducted face-to-face and 12 via audio/video conference. Interviews lasted an average of 50 minutes. We aimed for a diverse sample of interviewees to obtain a broad perspective, including participants were from India (8), Finland (4), Iran (3), Germany (1) and USA (1). Participants had a mean experience of around 6 years in varying roles and industries.

TABLE I. INTERVIEWEES CHARACTERISTICS

ID	Position	Industry	Experience (Years)
IC01	Developer / Tester	Telecommunication	9
IC02	Developer	Software development	3.5
IC03	Developer	Software development	2
IC04	Developer	Telecommunication	10
IC05	System Architect	Marketing	9
IC06	Developer	Digital broadcast service	5.5
IC07	Researcher / Developer	Finance	5
IC08	Developer	Telecommunication	4.5
IC09	Developer / Tester	Software development	5
IC10	Developer	Marketing	10
IC11	Developer	Software development	3.5
IC12	Developer / Tester	Oil and gas	7
IC13	Developer / Tester	Oil and gas	6
IC14	Tester	Engineering and consulting	3.5
IC15	Tester	Software development	3
IC16	Developer / Tester	Software development	6.5
IC17	Tester	Telecommunication	12

The second author transcribed the interviews verbatim from audio recordings (preserving original grammar, verbal static, etc.). All quotations provide below reflect exactly, or as closely as possible, what participants said.

All the transcripts were coded line-by-line by the second author using Nvivo[3]. Specifically, we used an integrated coding approach [24]; that is, a combination of inductive and deductive coding where an initial list of categories based on our research questions helped us develop codes inductively. Codes related to each category were combined to form themes, where a theme was seen as a high level conceptualization of multiple codes grouped together [25]. As a reliability check, the first author reviewed all of the coded scripts and subsequent themes.

III. SYSTEMATIC MAPPING RESULTS

The earliest included primary study was published in 1992. Interest increased significantly in 2008 and has remained uneven but high ever since (see Fig. 1). Because our search was conducted up to November 2015, the number for 2015 may be depressed.

Of the 84 primary studies, 70 were published in journals with the rest conference proceedings, and 69 reported empirical studies. Of these, 12 conducted in an industry setting, while 57 were conducted in laboratory environments. Below, primary studies are cited as [S01] to [S84] to distinguish them from regular references.

[1]For a complete list of primary studies, see http://bit.ly/2kgl0lX
[2]The questionnaire is available at http://bit.ly/2rcUKwh
[3]Nvivo is available from www.qsrinternational.com.

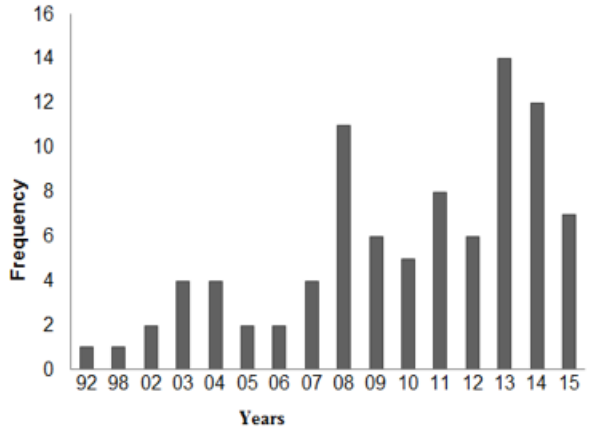

Fig. 1. Publication distribution per year

TABLE II. CONCEPTUALIZATION OF CREATIVITY IN SE

Definition Elements	References
Novelty and Utility	S14, S21, S23, S25, S48, S49, S59, S62, S66, S69, S74, S83, S44
Combining existing ideas	S33, S58
Number of developed features	S15
Deviation from usual pattern	S45
A process for idea generation	S68
Value addition	S77
Ill-defined problem	S74

A. How is creativity conceptualized in SE?

Out of the 84 primary studies, 19 papers attempted to define or conceptualize creativity (Table II). Consistent with Amabile's interpretation of creativity [26], 13 primary studies mention novelty and utility of a product as important dimensions.

Regarding the six P's of creativity (see Section I), 13 articles conceptualize creativity primarily on the *product* dimension. For example, emphasizing the number of product features [S15] and value-addition [S77] indicate a focus the *products* aspect. Two primary studies [S9], [S43] at least partially conceptualize creativity in terms of the person dimension. Only one primary study clearly emphasized creativity as a *process* [S68]. One article emphasized ill-defined problems [S74], which implicitly acknowledges the creative process. None of the articles focus on *place*, *persuasion* or *potential*.

B. What factors influence creativity in SE?

The approaches to improving creativity can be divided into two broad categories: adopting specific practices [S03], [S10], or modifying various factors that, in turn, affect creativity [S22], [S23]. Many different practices and factors have been investigated (see Tables III and IV).

Appearing in 30 primary studies, *brainstorming* is the most studied creativity practice. For example, brainstorming is effective for exploring creative ideas on project requirements [S23], [S61]. *Crowdsourcing* [S81] and *idea exploration* [S12] are also used to explore diverse ideas, increasing the chances of creative output. Similarly, some software organizations use explicit workshops to foster creativity among employees [S10], [S28]. More generally, *Agile* [S11], [S21] and *open source software* development approaches [S04], [S13] appear to promote interaction and *idea exploration*, increasing creativity.

TABLE III. PRACTICES INFLUENCING CREATIVITY

Practice	References
Brainstorming	S03, S07, S09, S10, S13, S14, S16, S19, S21, S22, S23, S24, S26, S29, S33, S34, S38, S43, S47, S54, S55, S61, S62, S67, S68, S70, S76, S79, S83, S84
Agile	S04, S10, S13, S26, S28, S33, S34, S35, S46, S47, S52, S65, S69, S78, S79
Sketching	S17, S22, S28, S30, S36, S38, S47, S54, S55, S56, S57, S61, S71, S72, S73
Open source software	S11, S21, S25, S29, S34, S40, S71, S79, S81, S82
Workshop	S10, S28, S55, S59, S66, S67, S68, S76, S83, S84
Scenarios	S22, S33, S34, S45, S56, S59, S67
Creative problem solving	S06, S10, S31, S37, S66, S67
Designing	S17, S31, S47, S57, S72
Unfamiliar connection	S31, S45, S55, S58, S70, S83
Idea exploration	S12, S16, S51, S55, S83
Analogies	S10, S14, S22, S30, S68
Mind maps	S32, S41, S80
Crowdsourcing	S42, S54, S81
Transformational approach	S47, S67

TABLE IV. FACTORS INFLUENCING CREATIVITY

Factors	References
Collaboration	S02, S03, S07, S09, S10, S13, S15, S22, S23, S25, S28, S29, S31, S33, S34, S37, S42, S45, S49, S52, S53, S55, S58, S59, S61, S62, S66, S71, S75, S78, S81, S84
Communication	S02, S04, S05, S15, S18, S22, S26, S28, S29, S33, S34, S36, S37, S42, S43, S49, S52, S61, S62, S65, S75, S77, S81, S83
Domain knowledge	S03, S09, S10, S21, S23, S25, S27, S29, S43, S48, S49, S50, S55, 591, S62, S63, S67, S70, S71, S75, S81
Positive affective state	S21, S23, S24, S28, S39, S40, S45, S49, S50, S52, S59, S64, S65, S70, S81
Extrinsic motivation	S01, S04, S26, S33, S28, S34, S35, S40, S42, S49, S50, S78, S81
Time pressure	S06, S10, S16, S24, S26, S33, S34, S37, S49, S59, S66, S68, S78
Flexibility	S01, S04, S20, S22, S27, S28, S38, S48, S49, S58, S60, S61, S66
Relationship and trust	S07, S33, S37, S49, S52, S55, S70
Stress and pressure	S01, S34, S62, S66, S75, S76
Constraints / conflicts	S07, S26, S33, S34, S37, S76
Cultural diversity	S13, S18, S37, S40, S49
Task structuring	S06, S07, S23, S64

Sketching, meanwhile, involves visual manifestation of an idea to foster creativity, especially in software design [S17], [S38]. A similar rationale supports the practice of *designing*, where designers utilize visual aids of *sketching* to generate creative outputs [S17], [S31]. *Mind maps* is another practice relying on visual definition of ideas and concepts, and making connections to produce creative artefacts [S32]. Visual representation of an idea promotes communication among developers to initiate a practice called *creative problem solving (CPS)*, which leads to better

creative thinking [S10], [S67]. CPS is the mutual process of *divergent thinking* (exploring multiple domains for solutions) and *convergent thinking* (picking the most appropriate solution) [27] to assist in creativity or creative thinking [7], [28]. Practices such as *unfamiliar connection* [S31], *analogies* [S10], and *transformational approach* [S47] encourage the utilization of familiar elements in many unconventional ways to explore creative ideas [S47], [S67].

Collaboration and *communication* are the two most investigated factors influencing creativity. *Collaboration,* mentioned by 32 primary studies, helps combine knowledge from diverse disciplines to generate creative ideas [S10], [S22]. Highlighted by 24 primary studies, appropriate *communication* within a group or across multiple groups helps to remove barriers, improves collaboration, encourages learning, and plays a crucial role in inducing creativity [S33], [S52].

Domain knowledge is important for creativity [S62], [S63]—especially producing ideas that are effective as well as novel. *Affective states* (moods and emotions) are intrinsic factors that can induce creativity [S28], [S39]. Positive affective states enhance creative performance, while negative affective states impede it [S50], [S59].

Extrinsic motivation driven by reward systems, culture, relationship and trust can also influence innate factors such as affective states, thereby influencing creative performance [S23], [S27]. Developers' flexibility in project execution can also enhance their creative performance [S01], [S21]. Restrictions such as *time pressure*, *stress*, *resources constraints,* rigidity and authoritarian management styles contrastingly inhibit creative thinking [S62], [S66].

C. How is creativity measured in SE?

SE studies have adopted several approaches to assessing creativity (Table V). Four of the primary studies operationalized creativity by counting new features added (particularly to open source software products) [S11], [S15], [S82], [S84]. Creativity can also be operationalized as the number of conceptual ideas generated [S21] or ratio of enhancements to bugs resolved in a code [S15]. Subjective assessment of perceived novelty [S18] or quality [S40] of ideas or code is also used. One study used the '*Consensual Assessment Technique*', where multiple domain experts assessed the creativity of a product [S50].

Williams' test [29], assessing fluent thinking, flexible thinking, original thinking and elaborative thinking, is also reported to measure creativity [S9], [S43]. It is the only measurement approach we encountered that evaluates the creativity of a *person* rather than *product*.

TABLE V. APPROACHES TO MEASURE CREATIVITY

Creativity Metrics/Measurement	References
Number of added new features	S11, S15, S82, S84
Williams' creativity assessment test	S9, S43
Number of multiple ideas generated	S21
Measuring value, novelty based on diverse stakeholders' opinion	S18
Ratio of number of enhancements to the number of bugs resolved	S15
Fluctuations in quality as codes evolve	S40
Consensual Assessment Techniques	S50

IV. INTERVIEW RESULTS

Our integrated coding approach produced three themes, which roughly correspond to the three research questions (Table VI).

A. How is creativity conceptualized in SE?

Eleven interviewees perceived creativity as a solution (idea or product) that exhibits novelty, ease of use and value for the creator or for the company. Six interviewees described creativity as a productive processes leading to a simple yet valuable solution. For instance, interviewee 10 explained: "*creativity is to find a solution which … is less cost … get much value for the system … solves the problems of the customer … create anything with … less effort"*. This illustrates the numerous criteria practitioners associate with creativity. More broadly, interviewees' conceptualizations of creativity reflect the dual criteria of novelty and effectiveness discussed in Section I.

B. What factors influence creativity in SE?

Sixteen interviewees felt that they enjoyed the freedom to use the creativity practices of their choice at work. Of these, seven interviewees reported brainstorming [30] as the most used creativity practice. Interviewees felt that brainstorming multiple ideas or solutions helped practitioners to arrive at the best possible outcome.

The remaining nine interviewees mentioned several practices including online research, consulting experts, and experimenting with different ideas to enhance their creativity. Interviewee 13 explained: *"I played with many things … even talked to … one of the senior programmers … he gave me a couple of ideas."* Only one interviewee mentioned sketching to visualize a problem and facilitate creativity.

All of the interviewees mentioned factors that influenced or enhanced their creativity. For 13 interviewees, '*motivation'* was the key personality trait that influenced creativity. The need to be creative was extrinsically motivated by rewards, recognition, personal growth prospects, and team dynamics. Responses like, *"…perform better to get better pay,"* by Interviewee 14, provides evidence for this distinction. Four interviewees were intrinsically motivated by autonomy, self-satisfaction, learning or the opportunity to work across multiple domains. Interviewee 14 said simply,*" I just enjoy doing what I am doing,"* indicating a deep sense of intrinsic motivation.

Additionally, 12 interviewees singled out their workplace environment as influencing their creativity. Responses such as *"Nobody stops me from doing anything,"* (Interviewee 13) suggest autonomy as an important determinant of creativity. Interviewees felt that freedom from rigid routines and external pressures gave these interviewees the opportunity to be creative at work.

C. How is creativity measured in SE?

Of the 17 interviewees, only 10 reported using some sort of creativity assessment approach. Eight interviewees believed that creativity assessment was based on the perceived quality of their personal contributions, or the value those contributions can make to the company. One of these interviewees equated this value with company profits.

TABLE VI. EXAMPLE OF THEMATIC SYNTHESIS OF PRACTITIONERS' PERCEPTION OF CREATIVITY

Theme	Codes	Quotes
Novel, usable and value-inducing process or product	Creative product	"According to me creativity is making something that will help make someone's life easier, and making something that has not been made yet, or taking something that is already there, and modifying it and taking it to another level."
		"I like building systems, and I like building systems that do their job very well. And usually, I find beauty in simplicity"
	Creative process	"get maximum automations for the process in which I am working for…So to make the data which they are handling on a day-to-day basis in a much simplified way is my idea of creativity."
		"Propose a simple solution, finding simpler ways to fix something and use less resources and efforts"
	Novelty and usability	"It's more of, I think, usability…UX. That how does the user uses, how can we simplify things for users, the end users who are using the website and mobile applications"
		"... creativity is finding novel solutions and get them to work "
	Value	"…in our system, creativity is to find a solution which…it less cost…we get much more value for the system, and…less, actually, flow and…with a less effort and with a less complexity, and solve a big problem, it's creativity"
Empowerment, encouraging environment, and personal characteristics	Brainstorming	"yeah…they have brainstorming, you can say, sessions, where anyone can present their ideas"
		"we have brainstorming sessions, in which majority of the people are involved, and everybody is asked for an opinion"
	Freedom	"..Every 2 weeks we have 1 day for ourselves that we can do whatever you want. They really, like...it can be anything, and it's really good. You can do some cool stuff, and there."
		"Dividing the whole thing into smallest component and then testing it. This is where creativity lies"
		"so I played with many things...talked to one of this…one of senior programmers in our company...I did lot of research on stack overflow and other web sites."
	Visualization	"First I try to…sketch it on a board, and…I visualize it first…if all this is in my mind, I cannot decide it very well. So I try to visualize it on the board"
	Creativity opportunity	"Yes, it does. It allows me to be creative because I can choose to test the way I want. There are no guidelines or rules to follow."
		"To be creative? Yes…yes, I think. I see it's as a balance, you know? At one hand, my job is not specifically defined. We don't have perfectly defined tasks that can be assigned to someone."
		"Sometimes, yes. Whenever I am implementing a feature, and I got the opportunity to explore more into the tool to achieve that functionality, that time I feel like, "yeah, today I learned a new thing."
	Motivation	"I think basically the increment…perform better to get better pay. And, basically, I want to learn new things, like, motivates me, like, something new, learn something new in the domain."
		"I just enjoy doing what I am doing. This is what my biggest motivation is."
		"Teamwork…for example, when we have problems, it's like a team…when we work well as a team, it just motivates me myself."
Subjective performance assessment	Performance based	"We have one portal, where we have to put our inputs, like what we have done in this year. So on that criteria they evaluate our performance, our creativity. "
		"They (*company*) see what kind of idea the developer and the technical people are coming up with. Then based on the entire ratings and the kind of visibility the project gets, then the company accordingly assesses the creativity of each and every individual."
	Based on perceived value and quality	"The first parameter, which is taken into consideration, is what benefit is it bringing to the company…The second thing is…how durable a particular solution is."
		"No, that's very…that's very seldom…I'd say that creativity…if it amounts to bottom-line, then, yes, but not as a standalone property of…of a developer."
		"…if you want to do something…do something really big that it's…you want to integrate it with their (*company's*) project, then of course they will evaluate or something."

The remaining seven interviewees reported that the quality and value aspect of creativity was based on their company's' arbitrary approvals made at their own discretion. As Interviewee 10 explained, *"usually, maybe one or two people who are handling most of the stuff…CTO is usually the one make this decision*." None of the interviewees indicated that creativity is a key criterion in their regular performance appraisals.

To summarize, we found that all the reported approaches to assess creativity were essentially based on the subjective evaluation of an individual or group of individuals. None participants used any specific tool, rubric, or practice to measure creativity.

V. TRIANGULATION AND DISCUSSION

Some important similarities and differences between the research and industry perspectives are evident.

Six practitioners and one (possibly two; see Section III A) primary studies conceptualized creativity in terms of a process. Two primary studies but none of the practitioners focused on the creativity of the person doing the work. At least one practitioner, but none of the primary studies emphasized *place* (i.e., the impact of work context). Neither studies nor practitioners seem to consider persuasion or potential.

Both communities conceptualize creativity primarily in terms of creative *products*. However, while most research seems to embrace the dual criteria of novelty and effectiveness, many practitioners appear unconcerned with

either or both. Practitioners, moreover, suggest many dimensions of product creativity (e.g. simplicity, marketability, ease of use), which appear to conflate creativity with a more general notion of quality. This suggests some degree of confusion among SE practitioners.

The key concern here is that both researchers and practitioners seem to adopt a specific view of creativity implicitly, without acknowledging that creativity can be a process, a personality trait, an attribute of a product, a property of an environment, etc. For example, if a practitioner and a researcher are discussing how to assess creativity, but one wants to assess products while the other wants to assess people, and neither party explicates their perspective, confusion is inevitable.

From a research perspective, this confusion hinders developing a comprehensive understanding of the concept of creativity in SE. It furthermore promotes creating silos in the research community.

From an industry perspective, this confusion impedes meaningful attempts to assess creativity. For example, a software project manager who googles *How do I assess creativity?* might intend to assess the creativity of software products, but will likely find techniques for assessing the creativity of people. Without a comprehensive understanding of creativity, it is not obvious that we have to specify what kind of creativity we want to assess. All of this decreases the chances of adopting evidenced-based creativity practices or scientifically valid assessment techniques.

Meanwhile, of the numerous and diverse creativity techniques available, *brainstorming* and *sketching* are the only two mentioned by both the primary studies and interviewees. Brainstorming is clearly the most popular creativity practice in both groups. Sketching was studied by 15 primary studies but mentioned by only one practitioner.

The remaining practitioners adopt a combination of approaches to influence creativity, mainly owing to the freedom they enjoy at work. Despite these differences, some of the practices were very closely related to the practices of *CPS* [S06], [S10], *unfamiliar connection* [S31], [S45], and *idea exploration* [S12], as reported in the SE research literature. This suggests that practitioners (or at least, our interviewees) are not aware of state-of-the-art techniques and practices for enhancing creativity.

Besides the techniques of *brainstorming* [S26], and innate factors of *intrinsic motivation* [S27] and *domain expertise* [S65] to influence creativity, similarities between the literature and interviewees are sparse. Most specific techniques in the literature were not mentioned by practitioners. For example, none of the eight interviewees who are heavily involved in testing mentioned practices that should improve creativity such as testing code without any pre-specified test-cases [S12], [S51]. Interviewees seemed unaware of the numerous creativity assessment approaches described in the literature, other than subjective assessment of creativity by managers.

To summarize, both interviewees and primary studies exhibit limited understanding of creativity. Dimensions of creativity other than product creativity remain under-researched in the SE literature. This is problematic because most creativity practices and factors operate through processes (e.g. scenarios, analogies) or people (e.g. affective state, motivation). More collaboration between the two communities is clearly needed. This can be facilitated by action research, grounded theory, case studies and participatory design. Moreover, more attention to creativity in SE education could produce substantial benefits [31].

These recommendations should be interpreted in light of several limitations. Despite following established guidelines [20] and employing multiple expert judges, both inclusion and analysis of primary studies are intrinsically subjective. For example, we excluded the substantial literature on innovation to control scope. The interview study, meanwhile, uses a convenience sample and therefore does not support statistical generalization. Moreover, social desirability may have biased interviewee comments and qualitative data analysis however structured is always subjective.

VI. Related Work

In SE, creativity has predominantly received attention in the context of RE [4], [32], software design [33], Agile development [4], collaboration [12], team dynamics [S37], and open source [S40]. In RE, meanwhile, creativity workshops are used to enhance creativity and provide clarity for requirements structuring [4], [8], and generate novel requirements [34]. In software design, interactive collaboration techniques ostensibly produce highly creative designs [33].

Amabile's definition of creativity as "*production of novel and useful ideas in any domain*" [26] is the most widely accepted interpretation of creativity (e.g. [35], [13]). Amabile perceives creativity as an interplay between expertise, creative thinking and task motivation. Other less explored aspects of creativity include appropriateness [36], value [37] or the social relevance of a solution or an idea [38]. These all focus on *product* creativity. Of the six P's, most creativity research seems to focus on product creativity and the creative process [39].

Concerning creativity practices, *brainstorming* is widely regarded as the most popular [40] (consistent with our findings). Several other practices are all based on a sequence of divergent, followed by convergent, thinking. Divergent thinking refers to generating many, diverse ideas. Convergent thinking refers to focusing on the best idea(s). This dichotomy is the basis of creative problem solving [30], the 5Ws & H model [24], analogy/metaphor – a creativity inducing technique where an individual or a group tends to find an innovative insight about the problem by establishing similarities between two things that are otherwise dissimilar [24], and wishful thinking – a creativity improvement technique where ideas and solution designs are expressed in terms of 'wishes' or 'fantasies' [41] [~~45~~].

Several factors that can induce or enhance creativity have been identified. For instance, *motivation* directly influences creativity [26]. Intrinsic motivation, in particular, is associated with more creative ideas [42]. Extrinsically motivated people, in contrast, tend to adopt the most direct path to a seemingly good solution. This efficiency however avoids divergent thinking and therefore impedes the opportunity to be creative. Intrinsic motivation can be facilitated by an environment that encourages personal empowerment, risk-taking and free flow of diverse ideas, possibilities and facts [36]. Intrinsic motivation is also associated with positive affectivity (e.g. enthusiasm) [43], which in turn enhances creativity [7], [43]. However, some

research suggests that negative affectivity (e.g. anger, contempt, disgust, guilt) can also positively influence creativity [44], [45].

Creative problems are often initially complex, ill-defined and poorly structured [46]. Imposing structure on these ill-defined problems (e.g., by writing requirements) can hinder generating creative conceptual designs [47]. Domain knowledge, in contrast, may be necessary for creative performance. However, there is no consensus as to whether domain-specific knowledge (knowledge specific to one particular domain) influences creativity more positively than domain-general knowledge (knowledge spanning multiple domains) [48], [49].

Turning to assessment, subjective judgment of creative products by experts or peers is the most commonly used method of assessing creativity [42], [49]. However, judges often disagree, undermining measurement validity [50]. Furthermore, the creativity of a product is fundamentally rooted in its context [43], [51]. Objective creativity metrics meanwhile remain both under-investigated and highly contested [43], [52]. The Torrance Tests of Creative Thinking appear to be the most popular approach to assessing the creativity of an individual or group, despite Torrance's own view that the tests do no capture all aspects of an individual's creativity [53].

VII. Conclusion and Future Work

In summary, we conducted a multimethodological study to investigate how creativity is understood, improved and assessed in SE research and practice. This study makes two main contributions:

1) It demonstrates that both research and practitioners implicitly adopt limited views of creativity (usually product creativity) without acknowledging other perspectives (person, process, place, persuasion and potential).

2) It illuminates a research practice gap: SE practitioners appear oblivious to the myriad techniques for enhancing and assessing creative performance.

Our sample of 84 primary studies and 17 interviews support the intuition that creativity is an important topic of interest in SE. We found no widely accepted definition of creativity in SE research. However, in broad terms there is consensus that creativity is a cognitive process that produces novel or useful ideas. Practitioners, however, conflate creativity with numerous other quality attributes.

The most popular creativity technique is clearly brainstorming, and the most common assessment approach is subjective judgment of creative products. Practitioners express concern for autonomy and associate their freedom to direct their own work with creativity. Since autonomy is associated with intrinsic motivation, this is largely consistent with the research literature.

More research is therefore needed on at least four fronts: 1) objective creativity assessment; 2) understanding how creative processes manifest in software development projects; 3) how personality; creative potential, cognitive processes and work environment affect creative performance in software development; 4) the relationship between autonomy, motivation and creativity.

Finally, we want to stress the importance of not only collaborating with industry partners to disseminate and co-create creativity practices but also teaching creativity techniques in undergraduate computer science and software engineering programs. Both steps are essential for addressing the widespread confusion evident in this study.

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