Creative Collective Efficacy in Scientific Communities

Jing Wang, Umer Farooq, and John M. Carroll

Abstract Studying collective creativity is critical for understanding how groups, organizations, and communities innovate and progress over time. However, analyzing creativity at the collective level remains an open and challenging issue. We adapt Bandura's construct of collective efficacy to understand beliefs about collective capacities for creativity among individual members part of scientific groups, organizations, and communities. We describe our preliminary studies on the development and refinement of a collective efficacy scale for creativity, the factor analyses of the scale items, and the validation of the scale in path models. Our collective efficacy scale for creativity can be adapted for use by researchers interested in investigating the creative capacity of other communities of practice.

Introduction

Investigating creativity is always challenging. Analyzing creativity in cooperative work is even more difficult [1, 2]. Recent research on creativity has been expanded from individual level to collective level, including groups, organizations and communities within which individuals collaborate with each other. One of the issues in studying collaborative creativity is to directly observe and assess collective creative outcomes. Collecting such data is very costly; combining and interpreting them is often ambiguous because of their diversity and complexity. The cost and ambiguity are particularly high when the groups are distributed or ad hoc, as commonly seen in Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) [3].

J. Wang (✉) and J.M. Carroll
College of Information Sciences and Technology, The Pennsylvania State University, University Park, PA, USA
e-mail: jzw143@ist.psu.edu; jcarroll@ist.psu.edu

U. Farooq
Microsoft Corporation, One Microsoft Way, Redmond, WA 98052, USA
e-mail: umfarooq@microsoft.com

M. Lewkowicz et al. (eds.), *Proceedings of COOP 2010*, Computer Supported Cooperative Work, DOI 10.1007/978-1-84996-211-7_18,

In this paper, we present an alternative way to investigate collective creativity in scientific communities. We develop the construct of creative collective efficacy by adapting Bandura's [4] construct of *collective efficacy*, a measure that can predict group or community performance by assessing members' beliefs in achieving goals in the face of possible challenges. Since it is a domain-specific construct, we investigate collective efficacy in the context of long-term scientific collaboration. In scientific communities, creativity is valued and pursued by scientists in their routine daily work. Our focus on scientific creativity is everyday creativity, such as writing a research paper. It is also known as which is also known as "little C" [5], which is more typical than revolutionary accomplishments or occasional incident.

The contributions of our study are as follows: First and most importantly, it develops the construct of creative collective efficacy, which perhaps is a key attribute to understand the social sources of collective creativity and can be adapted to other similar contexts of interest. Second, it offers indications for cooperative system design. Tools can be designed to enhance beliefs in certain domain-specific capacities in our efficacy scale. They may facilitate creative achievements in those aspects. Third, it provides an approach to investigate creativity in naturalistic settings rather than artificial ones with fabricated tasks. Moreover, it integrates contextual factors and processes of group creativity into an integral construct, delineating collective creativity more comprehensively. Finally, it amplifies the applications of collective efficacy, the use of which is still rare (e.g., [6]).

This paper is structured as follows. First, we describe how collective creativity is operationalized into collective efficacy in the domain of scientific collaboration. We then present our studies to develop, refine and validate the creative collective efficacy scale. Finally, we discuss future work.

Collective Efficacy

Collective efficacy is a psychometric construct that has not been adapted to investigate collective creativity. As defined in social cognitive theory, self-efficacy is perceived beliefs about one's capacity for specific achievements, given domain-specific obstacles [4]. We are analyzing the social construct of perceived collective efficacy, an extension of Bandura's concept that captures a member's beliefs about the collective capacities of a group, organization or community.

Efficacy is distinct from other general-purpose measures of self, such as self-concept, self-worth, and self-esteem. It is specific to a task or a domain [4, 7] and concerned with specific personal capabilities. Thus it is a more powerful predictor of individual behaviors than those self-worth conceptions [4, 8]. Another characteristic of efficacy judgments is that they are about what individuals believe they *can* do, rather than what they *typically* do, what they *have* done or what they *will* do. These beliefs influence the trajectory of action individuals choose to execute and the effort they spend on the execution [4, 7].

The scheme of efficacy items consists of two components: (1) a specified capacity in the domain of interest, and (2) a potential obstacle to achieving the goal. An example of regulating eating habits could be "I can maintain a healthy diet on a regular basis even when faced with appealing highfat foods in the supermarket" (adapted from [9]). In the example, the capacity is to "maintain a healthy diet on a regular basis" and the obstacle is "when faced with appealing highfat foods in the supermarket". In efficacy scales, belief in one's capacity is represented by Likert-scale ratings of agreement with the assertion of the capacity, given the assumption of the obstacle. The composite of efficacy items may appear to stretch traditional survey design principles because it has two parts; however, this is part of the specification and it sets up a concrete scenario of exercising efficacy for one's conjecture.

Collective efficacy extends self-efficacy to the beliefs about the collective power to produce desired joint outcomes [7]. Bandura [4] demonstrates that group members' beliefs about their shared capacities predict their performance as a group, similarly as self-efficacy. An illustration of collective efficacy from managing family could be "My family can celebrate family traditions even in difficult times" [9]. Another example from community managing conflict could be "Our community can enact fair laws, despite conflicts in the larger society" [6].

According to the properties of efficacy judgments, collective efficacy is promising and appealing for understanding collective creativity for at least three reasons. First, members' beliefs about their group's creative capacities for various attainments indicate the group's possible action towards those attainments. Creativity is a complex but important human capacity. Creativity as the capacity of groups, organizations, or communities is even more complicated. Collective efficacy provides an approach to understand collective creativity, particularly its social sources. Although self-efficacy has been applied to understand employees' creativity in firms [10] and analyze children's creative productivity [11, 12], collective efficacy have not been utilized for investigating either collective creativity or on creativity in the context of scientific communities. Second, collective efficacy is an indirect and relatively easy measure to assess, and has strong correlation with key aspects of behavior and performance. Measuring actual performance directly is difficult when interrogating complex capacities. The difficulty increases when evaluating performance of collective agencies. For instance, how can one predict when and where the interaction of most interest is going to happen [3]? Such difficulty is common in HCI and CSCW where computer-mediated behavior, often collaborative and distributed, is the focus. Finally, efficacy is task and domain specific. Thus it is appropriate for studying creativity, a construct that is highly contextualized.

Study Context and Scope

We are particularly interested in creativity within the context of scientific communities. The outcome of scientific creativity in our view is new knowledge production that is recognized as innovative by the relevant community [13].

This new knowledge can be produced by individuals (e.g. researchers), groups (e.g., one's research lab such as HCI), organizations (e.g., one's department such as computer science), and communities (e.g., one's network of peers such as the SIGHCI listserv).

This study mainly focuses on collective creativity at group level (i.e. research groups), which consists of individual intellects and interacts with its social environment–the context of the organizations and communities. Given this conceptualization, we integrate Csikszentmihalyi's systems model of creativity [13] and social psychological findings on group collaboration and creativity [14–16] to delineate the capacities and obstacles for creative collective efficacy. We expect that such theoretical foundation and integration can help construct comprehensive efficacy assessment to achieve good predication of creative performance.

The Creative Collective Efficacy Scale

As Bandura suggested [9], efficacy scales must be "tailored to activity domains and assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain". Our domain, group creativity in scientific communities, is associated with various group characteristics and group process factors [17], and is affected by its social environment. Efficacy assessment for research groups can be linked to the factors affecting group processes and groups' interaction with their social environment because groups can exercise some control over these factors [9]. Therefore, we operationalize *creative collective efficacy* (CCE) scale on the basis of Csikszentmihalyi's systems model of creativity [9] as well as the studies on group creative processes [15] synthesized and contextualized by Farooq et al. [14, 16].

Part of our CCE scale is concerned with groups' interaction with their social environment. According to Csikszentmihalyi [9], creativity is situated in its social systems: The domain transmits rules and practices to the individual and the individual produces novel variation in the domain's content; this variation has to be evaluated and selected by the field for inclusion in the domain. Several societal conditions in this interaction affect the incidence of creativity. Without some form of social evaluation, it would be impossible to distinguish novel variations that are simply bizarre from those that are genuinely creative. A material surplus also gives a society the advantage of creativity occurrence. A wealthier community is able to make information more readily available. Such a community allows for a greater rate of specialization and experimentation, and provides more opportunities to reward and implement new ideas than subsistence societies. Moreover, in order to be accepted by their larger community, individuals' variation has to surpass social inertia and the protective boundaries around technical procedures, knowledge base, etc., which Csikszentmihalyi names "*the memes*" [13].

Different from individual creativity described in Csikszentmihalyi's systems model, group creativity is also characterized by its dynamic processes in which

individuals cooperate with each other to approach joint creative outcomes. Therefore, the other part of our CCE scale depicts aspects that affect group creative processes.

Research on group creative processes suggests that divergent thinking and convergent thinking, social influences, information sharing, and reflexivity all influence group creativity [14–16]. Divergent thinking is the process of pooling different perspectives and generating alternative solutions, while convergent thinking allows groups to funnel down various alternatives and integrate them into one. Though one person can take multiple perspectives on a problem or task, a wider range of perspectives is more likely to emerge when several members approach an issue or problem from different angles or backgrounds [18]. Other than divergent thinking, groups also have to reach consensus for group creativity to occur. Nevertheless, available research results demonstrate that groups rarely achieve the level of the sum of the individuals [19]. Groups desire consensus without efforts on critical evaluation and integration. This suboptimal performance partially results from groupthink, which arises from situations like homogenous group members, strong and directed leadership, group isolation, and high cohesion [20]. Moreover, when the majority opinion holders achieve influence and exert social influence on the minority opinion holders, the minority would conform to the majority so as to attain uniformity [21]. Other than those ideation processes, group creativity also involves information sharing as well as metacognitive process. One necessary condition for creativity is that group members contribute their domain-specific knowledge and engage in sharing their unique information [22]. Typically, groups resort to common information pooling because members fear the criticism from other group members or because they are forced by other social influences such as normalization [23]. Group reflexivity include reflection, planning and action [24]. Knowing how well one is doing is essential for the one to work creatively [25]. Reflection generally consists of attention, awareness, monitoring, and evaluation of the object of reflection [24]. In particular, reflection requires evaluative and critical thinking, which is an important element in creative thinking [22]. Furthermore, selected ideas must be not only novel but practically feasible as well [18].

Procedure

We developed our CCE scale by reflecting on groups' creative scientific processes, their interaction with other groups, and their interaction with their scientific communities. Scale items were iteratively reviewed, critiqued, and revised during weekly research meetings over more than 1 year. To refine the CCE scale we administered two rounds of online surveys. Participants of both the surveys are researchers working in computer and information sciences related areas, and the second round recruited a larger number of participants. Having postulated on the results and feedback from the first round survey, we revised the problematic

items and adapted the structure extracted from the first version of scale into our second version. The second round of survey confirmed the structure and validated our scale.

An Exploratory CCE Scale

As an exploratory stage, the first version of CCE scale consisted of 17 items. Ten of them are based on Farooq et al.'s [14, 16] framework of group creative processes in scientific collaboration. The other seven are based on Csikszentmihalyi's [13] systems perspective of creativity. Fifty-five respondents were researchers working in computer and information sciences related areas from three colleges at a large university. More than 70% of them were graduate students. Sixty percent of the participants were at the age between 21 and 30. They rated their agreement on a nine-point Likert scale, indicating their levels of agreement from strongly disagree to strongly agree. We chose nine points rather than fewer points in order to obtain a more elaborate distribution of responses, preventing variation being dismissed. After principal component analysis and principal axis factoring on the scale, five items were pruned and four factors were extracted. Table 1 shows the other 12 items on the scale and their corresponding factors in principal component analysis (We did not include the pattern matrix generated by principal axis factoring method in this paper because of the space limit).

We conducted exploratory factor analysis on the responses ($N = 55$) from the first round of survey by using principal axis factoring with direct oblimin rotation. Principal axis factoring is the most commonly used exploratory factor analysis method in social and behavioral research. We also applied principal component analysis to the efficacy ratings. The same structure of the scale as the one presented in Table 1 arose. We chose an oblique rotation method over orthogonal rotation methods because factors extracted should be correlated according to the previous creativity studies as described at the beginning of Section The Creative Collective Efficacy Scale. Table 2 shows the correlations between the factors we extracted. These intercorrelations are not approaching zero though we controlled them to be low. Thus oblique rotation is appropriate for our data.

Four factors emerged from our first version of CCE scale according to the rules of thumb for determining the number of factors (including both eigenvalue one as the cut-off value and the beginning point of eigenvalues levelling off as the cutting point). The four factors are interpreted as "*Extrinsic Evaluation*" (the field impacts on incidence of creativity and societal recognition and evaluation on group creativity), "*Idea Integration*" (group's convergent thinking and expertise integration), "*Reflexivity*" (group's reflection and evaluation on objectives and processes) and "*Diversity*" (group's divergent thinking and diverse member composite) in the order presented in Table 1. These factors are well supported by previous studies in creativity, representing our perspective from group dynamics (i.e. idea integration, reflexivity and diversity) and its social context (i.e. extrinsic evaluation). The contributions of each factor to explaining total variance are listed in Table 3.

Table 1 Structure matrix of rotated factors in Version 1 of CCE scale (Principal Axis Factoring; Oblimin with Kaiser Normalization, Delta = –0.5)

	Factor			
	1	2	3	4
Our research group is fully capable of acquiring external research funding even with the stiff competition from other researchers in our field.	**0.833**	–0.339	–0.234	0.355
Our research group can publish novel results in highly rated journals despite the rigorous review process.	**0.727**	–0.262	–0.556	0.464
Our research group can decide among multiple ideas even though the evaluation criteria are not clear.	**0.630**	–0.362	–0.411	0.322
Our work can become recognized as a contribution to the field despite the orthodox boundaries formed by long-standing and senior researchers in the field.	**0.585**	0.032	–0.337	0.384
Members in our research group are willing to share their unique ideas without fear of criticism from the group.	0.144	**–0.870**	–0.393	0.429
Our research group can take advantage of minority ideas even though they can be easily dismissed.	0.433	**–0.857**	–0.520	0.363
Our research group can converge on a single idea even though each member tends to see things through the lens of their own experience and expertise.	0.433	**–0.713**	–0.262	0.400
Our research group can effectively reflect on shared objectives, strategies, and processes even when we are against tight deadlines.	0.414	–0.407	**–0.816**	0.435
Our research group can critically evaluate and integrate multiple ideas into a single research opportunity without compromising overall novelty.	0.303	–0.285	**–0.750**	0.208
Our research group can generate different perspectives even though majority of the group members have similar backgrounds.	0.547	–0.410	–0.485	**0.809**
Our research group can put selected ideas into practice even though some of the required resources like equipment are currently not available.	0.295	–0.271	–0.099	**0.723**
Our research group is capable of pooling unique ideas from group members even though the group would like to converge toward common and shared ideas.	0.322	–0.337	–0.537	**0.711**

Table 2 Factor correlation matrix in Version 1 of CCE scale (Principal Axis Factoring; Oblimin with Kaiser Normalization, Delta = −0.5)

Factor	1	2	3	4
1	1.000	−0.225	−0.350	0.382
2	−0.225	1.000	0.288	−0.300
3	−0.350	0.288	1.000	−0.308
4	0.382	−0.300	−0.308	1.000

Table 3 Rotated extraction sums of squared loadings in Version 1 of CCE scale (Principal Axis Factoring; Oblimin with Kaiser Normalization, Delta = −0.5)

Factor	Eigenvalues	Percent of total variance explained	Cumulative variance
1	5.245	43.705	43.705
2	1.113	9.276	52.982
3	0.753	6.274	59.256
4	0.689	5.738	64.993

The reliability of our entire CCE scale and each factor are strong. The overall reliability of the 12 items has Cronbach's Alpha value of 0.892. The Cronbach's Alpha values for each factor, "*Extrinsic Evaluation*", "*Idea Integration*", "*Reflexivity*", and "*Diversity*" respectively, are 0.785, 0.832, 0.744, and 0.812.

We followed up participants with open questions to examine whether any dimensions of group creativity were missing from our CCE scale. We asked participants to list three ways in which they and their research group are creative and three obstacles inhibiting creativity that their research group and themselves experience or may experience. Responses from total 11 participants illustrated similar scenarios in our scale items. Additionally, collaboration with other research entities and employing various methods to approach problems are also identified as creative capacities by respondents. Time constraint and distractions are the most emphasized obstacles that impede group creativity.

However, this scale is still problematic in several aspects. First, some factors do not have items cohesive enough: The second item with the high loading in factor "*Diversity*" (i.e. Our research group can put selected ideas into practice even though some of the required resources like equipment are currently not available.) depicts creativity in terms of its implementation and practice which should have stronger correlation with factor "*Reflexivity*"; the second item in factor "*Reflexivity*" (i.e. Our research group can critically evaluate and integrate multiple ideas into a single research opportunity without compromising overall novelty.) does not have strong contrast from factor "*Idea Integration*". Second, some factors do not have enough items. Factor "*Reflexivity*" only has two items, which is not adequate for a proper factor size. Finally, the validity of the scale was not sufficiently verified by the data collected.

By reflecting on these problems and feedback from participants, we speculated that we might have described multiple aspects in one item and the goal and obstacle may not be matched appropriately. Also the items were framed too abstract for participants to assess. Therefore, we decided to decompose complicated items, match

the goal and obstacle more consistently, phrase the items more specifically, and employ other methods for factor analysis with consideration of factor correlation.

A Refined CCE Scale

We refined and expanded our CCE scale on the basis of the structure identified in our preliminary survey. Five categories of 16 items in total were generated before analysis, four of which were adapted from the four factors extracted in our first survey (i.e. *diversity, idea integration, reflexivity and extrinsic evaluation*) and the other one "*Intergroup Information Exchange*" was an expansion to connect group dynamics to its social context. This classification is our attempt to analyze the complicated creative processes, although these different categories interact and co-occur in actual group activities. Except for items about "*Intergroup Information Exchange*", the majority of the items derived from the items working well in the old scale, while some of them were revised to be more concise and comprehensible. The other items integrated the specific capacities overlooked in the first round survey but raised by participants in follow-up questions, e.g. capacities to approach problems by various methods and converging on one method, and obstacles like time constraint as well as coordinative distractions. We also tried to balance the structure of the scale as three to four items per each category. A full list of items is presented in Table 4.

The first four factors maintained the dimensions distilled in the preliminary survey: "*Divergent Thinking*" delineates group's ability to generate and take advantage of a variety of ideas, options, alternatives and methods corresponding to research problems; "*Convergent Thinking*" involves narrowing the set of diverse opinions into one by reaching consensus on the best idea or integration; "*Reflexivity*" refers to members' collective reflection on the group's objectives, strategies, and processes as well as their wider organizations and environments, and adaptation and implementation; and "*Extrinsic Evaluation*" is the acceptance and recognition by the community that ensures scientific creativity.

The last factor "*Intergroup Information Exchange*" is new in the refined CCE scale. As one of the key components of communities, groups in their social environment do not operate in isolation but interact with each other. They should be open to communicate and exchange information and values across organizational boundaries [17, 26]. On the one hand, delivering ideas to other groups is one way for groups to be socially judged and acknowledged as well as to obtain support and other resources [27]. On the other hand, when connected with other groups, a group can benefit from others' creative ideas via knowledge transfer or learning from indirect experience [28, 29].

Participants of this refined scale were recruited from subscribers of ACM-SIGCHI (the Association for Computing Machinery Special Interest Group on Computer-Human Interaction) and AIS-SIGHCI (the Association for Information Systems Special Interest Group on Human-Computer Interaction) mailing lists.

Among total 129 respondents, 55.4% are male while 44.6% are female. 62.8% respondents were from ACM-SIGCHI while 37.2% were from AIS-SIGHCI. 99.2% of the respondents had completed 4-year college education or above, and

Table 4 Version 2 of CCE scale with five categories

Five categories of CCE items
Divergent thinking
1. Our research group can generate different perspectives even though majority of the group members have similar backgrounds.
2. Our research group can apply a variety of methods to problems despite the human tendency to use the same approach over and over.
3. Our research group can seriously consider "minority views" though it might be faster to reach consensus by focusing only on the majority view.
4. Members of our research group can share ideas without fear of criticism from the group.
Convergent thinking
5. Our research group can integrate the unique ideas of different members even though it could be easier to just pick one idea.
6. Our research group can agree on a single idea even though each person tends to see things through the lens of their own experience and interests.
7. Our research group can concur on a method for approaching a problem despite variation in individual preferences and familiarities.
Reflexivity
8. Our research group can take the time required to reflect on the big picture despite deadlines and other distractions.
9. Our research group can decide among ideas even when the evaluation criteria are not completely clear.
10. Our research group can put ideas into practice even when some of the required resources are not available.
Extrinsic evaluation
11. Our research group can publish novel results in highly rated journals and conferences even though their acceptance rate is low.
12. Our research group is fully capable of acquiring external research funding even with the stiff competition from other researchers in our field.
13. Our work can become recognized as a contribution to the field despite the community inertia towards radical changes.
Intergroup information exchange
14. Our research group can incorporate ideas from another group even though it can be challenging for us to understand those ideas' context.
15. Our research group can convey our opinions to another group although it can difficult to fully communicate our value.
16. Our research group can cooperate with other groups on a project though we may have different practices from those groups.

almost half of the respondents (49.6%) had received doctorate degree. Half of the participants (50.0%) were between 31 and 50 years old, while 25% of them were between 21 and 30 years old. Overall, participants in our second round of survey were more experienced and accomplished researchers with diverse backgrounds than those in our first round of survey.

Item 12 had the lowest mean (5.61 out of 9; 14 of 16 item means were greater than 6) with the largest standard deviation (2.400; 13 of 16 item standard deviations were less than 2). This might suggest that acquiring research funding involves many other opportunistic elements than creative capacities. Another feature of these items is that all the three items from the category "*Convergent Thinking*" had means larger than 7 (11 of 16 item means were less than 7) with standard deviations less than 1.5 (the other item standard deviations were all greater than 1.5). It may

indicate that convergent thinking capacities we depicted are relatively easy to achieve so little variance of the collective efficacy in it was detected.

For confirmatory purposes, we conducted Confirmatory Factor Analysis (CFA) with maximum likelihood method provided by AMOS 16 to examine the structure of the refined CCE scale. Another advantage of CFA is to allow unconstrained correlation between factors, which is more appropriate for the structure we were investigating than the way we analyzed our preliminary CCE scale. The model we presumed did not achieve sufficient goodness of fit (χ^2 = 165.684, df = 94, CFI = 0.894, TLI = 0.847, RMSEA = 0.077[1]). To reach better goodness of fit, we tested other alternative models, keeping the latent-indicator relationships as unchanged as possible and deleting as few items as possible. The final model selected (Cronbach's alpha = 0.889) excluded item 4 and 5 with improved goodness of fit (χ^2 = 97.995, df = 67, CFI = 0.946, TLI = 0.915, RMSEA = 0.060). In this model item 16 was adjusted as an indicator for "*Extrinsic Evaluation*".

Item 4 and 5 were dropped out from the scale because they were unique from the items. Item 4 is more about information sharing which is relatively distinct from the five underlying factors in the scale. Moreover, the way it was phrased – using "members of the group" as opposed to "our research group" – might have amplified its uniqueness. Item 5 might have the problem of including too many dimensions in the single item. Though it was generated to emphasize integration of ideas, the expressions, "unique ideas" and "different members", may have implications to respondents that individual differences would inhibit such integration, which was not stated explicitly as the obstacle in this item. Instead, its obstacle was about groupthink. Table 5 shows the values of factor loadings (i.e. standardized regression weights)

Table 5 Reliability and factor loadings of refined CCE scale

Factor	Loadings
Divergent thinking (α = 0.681, CR = 0.703, AVE = 0.453)	
Item 1	0.441
Item 2	0.772
Item 3	0.755
Convergent thinking (α = 0.732, CR = 0.736, AVE = 0.540)	
Item 6	0.737
Item 7	0.788
Reflexivity (α = 0.651, CR = 0.669, AVE = 0.403)	
Item 8	0.582
Item 9	0.673
Item 10	0.648
Extrinsic evaluation (α = 0.723, CR = 0.734, AVE = 0.415)	
Item 11	0.521
Item 12	0.565
Item 13	0.758
Item 16	0.705
Intergroup information exchange (α = 0.613, CR = 0.618, AVE = 0.445)	
Item 14	0.666
Item 15	0.672

[1]CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = root mean square error of approximation. Usually when RMSEA smaller than 0.06 and the other indices greater than 0.9 the model is considered as fits good.

Table 6 Correlation between refined CCE factors

	Correlation
Extrinsic evaluation ' Intergroup information exchange	0.839
Reflexivity <-> Divergent thinking	0.751
Intergroup information exchange <-> Divergent thinking	0.799
Extrinsic evaluation <-> Divergent thinking	0.838
Intergroup information exchange <-> Reflexivity	0.989
Extrinsic evaluation <-> Reflexivity	0.828
Convergent thinking <-> Divergent thinking	0.860
Convergent thinking <-> Reflexivity	0.826
Convergent thinking <-> Intergroup information exchange	0.839
Convergent thinking <-> Extrinsic evaluation	0.744

as well as metrics relevant to reliability and construct validity for each factor (i.e. α=Cronbach's alpha, CR=Composite Reliability and AVE=Average Variance Extracted). Table 6 presents the correlations between factors.

Our examination on reliability and validity of our refined CCE scale indicates that the scale is fairly reliable and valid. The reliability of each factor, particularly internal consistency, is fairly high with Cronbach's alpha and composite reliability greater than or at least close to 0.7. The construct validity of this scale was tested in terms of both convergent validity and discriminant validity. The convergent validity of each factor was well purported since the loading of each factor was significant in t-tests ($\alpha = 0.05$). The discriminant validity measures the extent to which the latent variables (i.e. factors in this case) are different. The simplest way to evaluate discriminant validity is to examine whether correlation is larger than 0.85. According to this criterion, in our refined CCE scale all the values of correlations between factors except the one between "*Intergroup Information Exchange*" and "*Reflexivity*" were smaller than or close to 0.85, which indicates the discriminant validity is acceptable. The results of our examination also suggest further improvements for our CCE scale. Specifically, factors "*Intergroup Information Exchange*" and "*Reflexivity*" were a bit inadequately reliable. The discriminant validity between "*Intergroup Information Exchange*" and "*Reflexivity*" was poor. We also employed another two methods to assess the discriminant validity of each CCE factor: comparing AVE with shared variance and comparing nested models in Structural Equation Modeling (SEM). Both of them showed that the five factors in our refined CCE scale were not distinct enough from each other.

Other than improving the reliability and validity of our scale, more items should be added to factors "*Intergroup Information Exchange*" and "*Reflexivity*" because these two factors only have two items for each after scale adjustment.

Validation of CCE

Validating collective efficacy scale not only encompasses verification of its construct validity as an integral construct and the construct validity of each factor within its internal structure, but more importantly involves hypothesis testing on its

causal relationships with other variables [30]. The construct of collective efficacy in theory is interconnected with various factors. It can have "diverse effects on motivation, thought, affect and action, so there are many verifiable consequences that can be tested" [30]. Its causal relationship with actual outcomes and its ability of predicting conjoint creative performance are also appealing advantages for analyzing group creativity.

Given these requirements on efficacy scale validation, we examined the relationships between CCE and a variety of factors related to group creativity. We collected data about participants' research and collaboration behaviors, their personality characteristics and their group features. We are also interested in the role of information technology use in scientific creative collaboration. Its role may in the long term inform us of tool design for creativity support. Thus we asked participants about their Internet use in our survey as well.

We developed a series of path models to investigate the complex relationships between CCE and those factors we assessed. These models suggest that researchers with higher CCE are more engaged in group collaboration and produced more collective creative products. This adds evidence for the validity of the collective efficacy construct.

Path Models Using CCE as an Integral Construct

Other than CCE scale, our online survey collected indicators that may relate to CCE, including personality characteristics (e.g., 30-item Creative Personality Scale [14] derived from adjective checklist for creativity [31] and 18-item introversion scale [32]), the size of active collaboration circle (i.e. number of people the participant is recently cooperating on research), occupational status (e.g., full professor at a university, graduate student, and research associate/post doc), creative outcomes (e.g., number of individual publications, number of group publications in the last 3 years, and number of research projects individual involved in), co-authorship (i.e. percentage of coauthored publications in individual publications), effort (e.g., how much of working time is spent on research, how much of research time is spent on collaborating with colleagues), reading sources (e.g., frequency of professional reading, conference proceedings and academic journals), and Internet use (e.g., frequency of Internet use for interacting with research colleagues, and percentage of Internet use for group coordination, informal personal interaction, collaborative and individual work).

We conducted both conventional path analysis (every variable in the model is observed and directly measured) and Structural Equation Modeling (SEM) to develop our path models. In conventional path analysis, CCE is the mean score of the 14 items in our refined scale. Some of the variables, such as introversion and reading resources, were excluded in our path models because they were not correlated with CCE. Variables in the path models include (1) a set of exogenous variables, i.e. creative personalities, occupational status and number of recent research collaborators, (2) mediating variables, i.e. Internet interaction – frequency of

Internet use for interacting with research colleagues – and percentage of coauthored publications in individual publications, and (3) variables characterizing creative performance and researchers' behaviors to approach group creativity, i.e. creative outcomes and effort. The final path models are presented in Figs. 1 and 2.

Both models describe similar relationships between CCE and other variables. First, full professors report greater CCE than other researchers with lower occupational status. Full professors usually have more experience and have been more socially acknowledged in their field, so they are more confident in achieving those

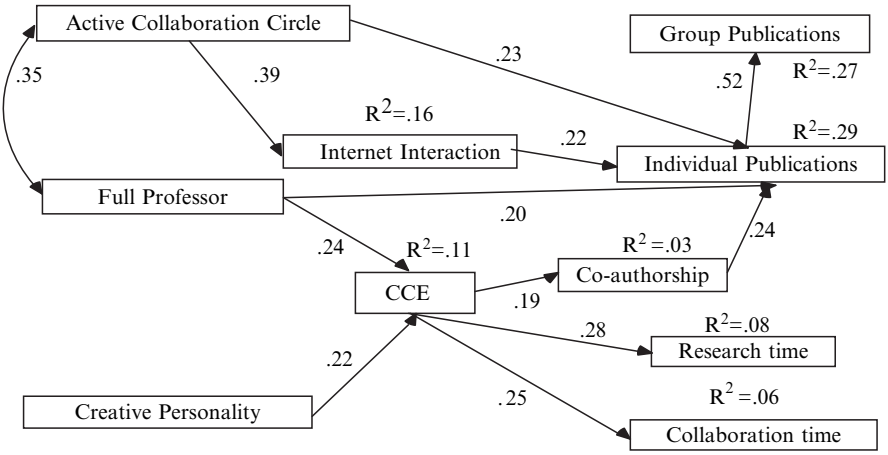

Fig. 1 Path model illustrating CCE involvement in creative activities using path analysis

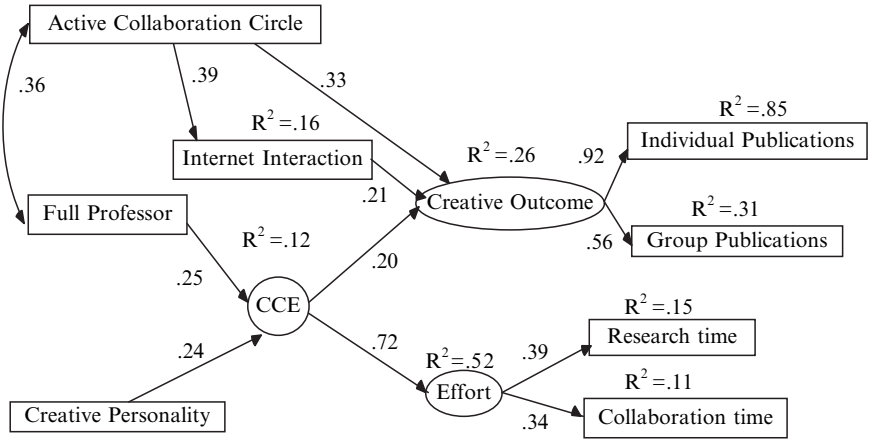

Fig. 2 Path model illustrating CCE involvement in creative activities using SEM (Ellipses denote latent variables and rectangles denote observed variables)

creative attainments. Most likely, they are also leaders in their research groups. They feel more responsible to facilitate group for creative accomplishments. They may have stronger intrinsic motivation and richer resources. Off the stress from tenure or status promotion, full professors probably devote themselves more to the research of their real interests. Second, people who have more creative personalities tend to believe more that the given attainments can be achieved. They may believe that their personal traits can facilitate group creative actions.

For the relationships between CCE and mediating variables, the path model using path analysis suggests that CCE is positively associated with the portion of coauthored publications in individual publications. Strong beliefs in group creative achievements may encourage researchers to contribute to their group creative activities by means of collaboratively producing publications with group members.

The two models also suggest that CCE has effects on the participants' research efforts and their actual creative outcomes. People who report greater CCE may be more encouraged to devote their work time to their research and their research time to collaborate with research colleagues. They may also commit themselves more to their group creative processes and activities. The commitment in turn is associated with both their individual and group creative productivity – number of publications. Although the number of publications can only partially represent creative outcomes, it served as a proxy measure for us to understand the relationship between CCE and scientific creativity. One interesting finding in our data set is that the self-report number of group publications was sometimes smaller than that of individual publications although the correlation between them was still positive throughout all the responses. It may be caused by several reasons: individuals might not count their publication that they attribute to their effort as publications of their group; individual might be involved in multiple research groups at the same time, from which they all produce papers but the number of group publications was only estimated for one of these groups; and individual researcher might have changed research group during the past 3 years and the group was referred to the current one. This in part reveals the difficulty of direct measurement on collective creativity.

As part of our interests, the role of information technology use in group creative activities was also illustrated by the two models. The larger the size of individuals' active collaboration circle, the more frequently they use Internet to interact with their colleagues. The direct effect of the circle size on creative outcomes may suggest that researchers with larger number of active collaborators may have more resources, or social capital, to produce more publications. Another side note for these models is the positive correlation between full professor occupation status and collaboration circle size, which may imply that full professors have more connections with other researchers.

Overall, the models provide encouraging demonstration with respect to CCE as a valid construct for collective creativity in scientific collaboration. They illustrate research group members' engagement in creative collaboration and in their self-report creative productivity.

Path Models Using CCE Factors

CCE's general role in the path models in Figs. 1 and 2 offers initial evidence that the construct is a useful variable in investigating collective creativity. To further articulate the scale's validity, we continued to examine the effects of each factor on group's creative performance by using path analysis and SEM.

With respect to the creative outcome variables we measured (i.e. publications), we found that they were only significantly correlated with the factor "*Extrinsic Evaluation*". The path model using conventional path analysis is shown in Fig. 3, which reached fair goodness of fit ($\chi^2 = 41.770$, df = 32, CFI = 0.928, TLI = 0.877, RMSEA = 0.049). The path model tested by SEM is shown in Fig. 4. It fits a little weaker than the one in Fig. 3 ($\chi^2 = 72.280$, df = 49, CFI = 0.900, TLI = 0.840, RMSEA = 0.061), and one of its paths from the latent variable "*Effort*" to "*Collaboration Time*" is not significant enough ($p = 0.068$).

The involvement of "*Extrinsic Evaluation*" with other variables is similar with that of the CCE construct: people with stronger beliefs in their abilities to win extrinsic evaluation indeed had more publications, of both their own and their group. One interesting difference is the direct effect of active collaboration circle size on the factor "*Extrinsic Evaluation*". This may indicate that researchers collaborating with more people recently are more confident to gain support and recognition from their groups' social environment.

The other four factors were not correlated with the creative outcome variables, but three of them were positively associated with effort variables at different degrees (here each factor is represented by the mean score of the items with it):

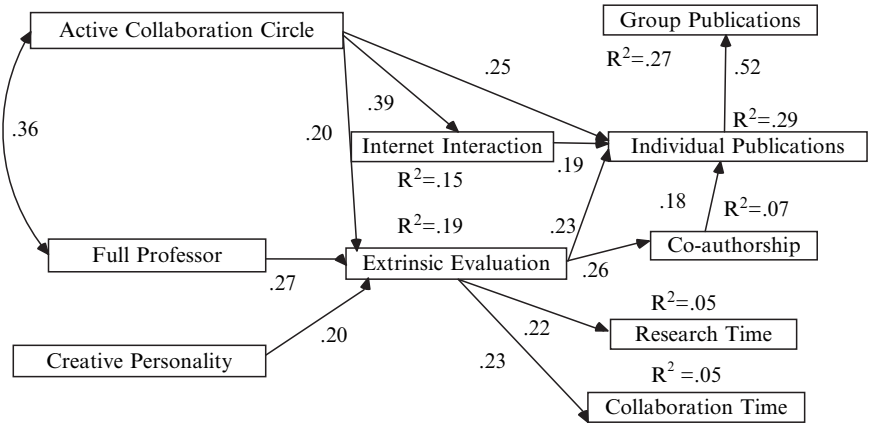

Fig. 3 Path model illustrating the involvement of extrinsic evaluation in creative activities using path analysis

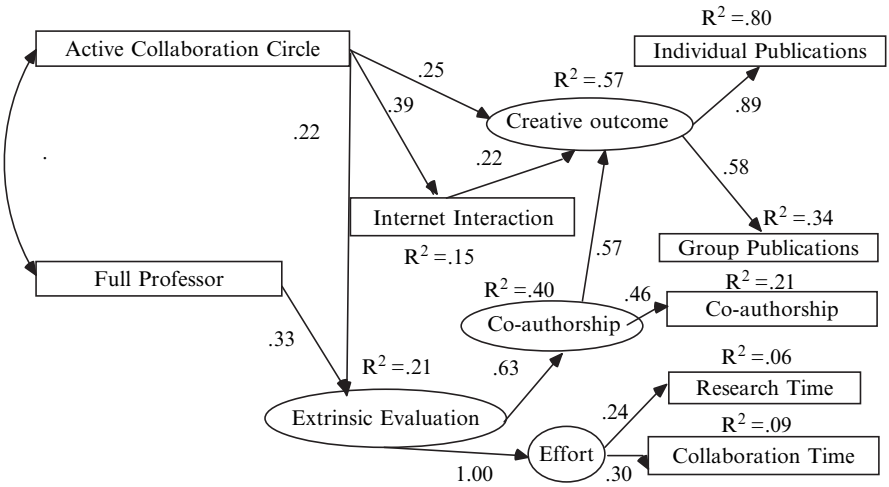

Fig. 4 Path model illustrating the involvement of *extrinsic evaluation* in creative activities using SEM

"*Divergent Thinking*" was correlated with both percentage of research time in work time ($r = 0.272$, $p = 0.003$) and percentage of collaboration time in research time ($r = 0.186$, $p = 0.048$); both "*Reflexivity*" ($r = 0.234$, $p = 0.012$) and "*Intergroup Information Exchange*" ($r = 0.205$, $p = 0.029$) were related to percentage of research time in work time. One possible reason for the difference of correlation with creative outcomes between these four factors and the "*Extrinsic Evaluation*" may be that "*Extrinsic Evaluation*" as beliefs in gaining societal recognition is more directly related to the final creative products – publications in our case. The goal in item 11 was even explicitly stated with respect to publications. Such difference suggests that CCE's structure still needs improvement (e.g., discriminant validity of each factor). The absence of association between "*Convergent Thinking*" and outcome or effort variables may manifest again that this factor is the easiest capacity among the five for groups to attain.

Though the validity of each CCE factor was not adequately purported by the variables we measured, the theoretical foundation for the substructure of this scale is still legitimate. Furthermore, the predicting power of CCE construct for collective creativity, as demonstrated in Section Path Models Using CCE as an Integral Construct, should not be dismissed. Our interpretation of the two sets of path models is necessarily provisional, but the findings about the relationships between CCE and its factors, personal characteristics, and creative performance and behaviors provide important and specific validation for the CCE scale. Further qualitative studies such as ethnography would improve our current interpretation of the results and enrich our understanding of creative scientific collaboration,

Discussion and Future Work

As one of the challenging issues emerged in creativity research, investigating collective creativity requires new methods and progress. Our studies present preliminary manifestation that *Creative Collective Efficacy* is a valid and useful construct for investigating collective creativity, particularly understanding its social sources. Our CCE scale was developed from theoretical frameworks and represents a comprehensive integration of collective creative capacities, though it did not include individual's inherent creative capacities which are less associated with social contexts. Although our study context was computer and information sciences, we anticipate that researchers interested in collective creativity can tailor our instrument to their specific study contexts. For example, our instrument can be used to study creative capacities in communities of practice [33]. A community of practice involves a set of socially defined ways of doing things in a specific domain: a set of common approaches and shared standards that create a basis for action, communication, problem solving, performance, and accountability. To adapt CCE scale to such a community, a software development community, we can keep the structure as well as most of the items in our current scale but only adjust terms for research into software production.

Our future directions to develop this scale include refining the multidimensional structure of CCE and improving its validation tests by introducing more variables that may relate to CCE and its factors. To refine our current CCE scale, we may have to enhance the discriminant validity of each factor, making the items in one factor more distinct from the ones in other factors. Some factors in our CCE scale do not have enough items. For instance, "*Convergent Thinking*" and "*Intergroup Information Exchange*" only have two items left respectively. Thus we need to create more items for them. Another concern is the little variation of items in "*Convergent Thinking*". Describing goals that are more difficult to achieve may increase the variation. We may also expand the variety of factors in the scale to augment its predictability of creative performance. For example, we did not create items with regard to developing shared objectives, which is also critical to group creativity [34, 35].

To enhance the validation of CCE and its usefulness in understanding creative collaboration, one option can be introducing more variables that may directly relate to CCE and also have established valid metrics. For example, as Bandura noted [30], efficacy can have effects on motivation and affect. One instrument available with respect to motivation and creativity is KEYS developed by Amabile et al. [36]. Another extension which might be more difficult is to appraise the performance of divergent thinking, convergent thinking and so on and test its relation with efficacy beliefs in those capacities. The set of exogenous variables can also be expanded by incorporating measures such as group composite. Group size as an indicator of group composite may contribute to both perceptions of collective efficacy and collective creative performance through their effects on coordination and cooperation [37, 38]. The mediating variables can also include other efficacy constructs to understand how they interact with CCE, for instance, creative self-efficacy.

An alternative design to test the validity of CCE construct is to compare groups with different CCE and examine whether they perform differently in terms of collective creative outcomes. A group's CCE can be assessed as either an aggregation of each group member's CCE or group members' consensus on it (tradeoffs of either way to measure collective efficacy are discussed in [7, 39]). The strength of this design is that groups' CCE is more directly associated with groups' attainments than individuals' CCE. Comparatively, greater CCE of an individual in our study cannot represent the whole group's level of CCE. Participants in this alternative design may also identify about which group they should report more easily. However, this approach also has its downsides, e.g., high cost of sampling a variety of groups with representative members.

Longitudinal studies would also be beneficial to examine the causal relationship between CCE and group creativity. The validity of CCE can be enhanced by considering temporal factors than measuring these variables at the same time, because collective efficacy is often augmented by mastery experience, e.g., previous creative performance may affect currently perceived CCE. Such studies will also enrich our understanding of how to enhance group creativity by tracking CCE evolvement.

In the long term, we also hope to develop cooperative systems that support creative collaboration within groups, communities and organizations by enhancing creative collective efficacy. Efficacy appears to purport their persistence level to cope with challenging circumstances that may impede their creative achievements [10].

Acknowledgment This research was supported by NSF SGER IIS-0749172. We thank Craig H. Ganoe and Shaoke Zhang for discussions about creative collective efficacy.

References

1. Mayer, R.E.: Fifty years of creativity research. In: Sternberg, R.J. (ed.): Handbook of creativity, Vol. 460. Cambridge University Press, New York (1999) 449–460
2. Mamykina, L., Candy, L., Edmonds, E.: Collaborative creativity. Communications of the ACM 45 (2002) 96–99
3. Neale, D.C., Carroll, J.M., Rosson, M.B.: Evaluating computer-supported cooperative work: models and frameworks. Proceedings of CSCW'04. ACM Press, Chicago, IL (Nov 2004) 368–377
4. Bandura, A.: Self-Efficacy: The Exercise of Control. W. H. Freeman, New York (1997)
5. Gardner, H.: Seven creators of the modern era. In: Brockman, J. (ed.): Creativity. Simon & Schuster, New York (1993) 28–47
6. Carroll, J.M., Rosson, M.B., Zhou, J.: Collective efficacy as a measure of community. Proceedings of CHI'05. ACM Press, Portland, OR (April 2005) 1–10
7. Goddard, R.D., Hoy, W.K., Hoy, A.W.: Collective Efficacy Beliefs: Theoretical Developments, Empirical Evidence, and Future Directions. Educational Researcher 33 (2004) 3–13
8. Pajares, F., Miller, M.D.: Role of Self-Efficacy and Self-Concept Beliefs in Mathematical Problem Solving: A Path Analysis. Journal of Educational Psychology 86 (1994) 193–203
9. Bandura, A.: Guide for constructing self-efficacy scales. In: Pajares, F., Urban, T. (eds.): Self-efficacy beliefs of adolescents, Vol. 5. Information Age Publishing, Greenwich, CT (2006) 307–337
10. Tierney, P., Farmer, S.M.: Creative self-efficacy: Its potential antecedents and relationship to creative performance. Academy of Management Journal 45 (2002) 1137–1148

11. Schack, G.D.: Self-Efficacy as a Mediator in the Creative Productivity of Gifted Children. Journal for the Education of the Gifted 12 (1989) 231–249
12. Beghetto, R.A.: Creative self-efficacy: Correlates in middle and secondary students. Creativity Research Journal 18 (2006) 447–457
13. Csikszentmihalyi, M.: Implications of a Systems Perspective for the Study of Creativity. In: Sternberg, R.J. (ed.): Handbook of Creativity. Cambridge University Press, New York (1999) 313–335
14. Farooq, U., Carroll, J.M., Ganoe, C.H.: Supporting creativity with awareness in distributed collaboration. Proceedings of GROUP'07. ACM Press, Sanibel Island, FL (2007) 31–40
15. Paulus, P.B., Nijstad, B.A.: Group Creativity: Innovation Through Collaboration. Oxford University Press, New York (2003)
16. Farooq, U., Carroll, J.M., Ganoe, C.H.: Supporting creativity in distributed scientific communities. Proceedings of GROUP'05. ACM Press, Sanibel Island, FL (2005) 217–226
17. Woodman, R.W., Sawyer, J.E., Griffin, R.W.: Toward a theory of organizational creativity. Academy of Management Review 18 (1993) 293–321
18. Milliken, F.J., Bartel, C.A., Kurtzberg, T.R.: Diversity and creativity in work groups: A dynamic perspective on the affective and cognitive processes that link diversity and performance. In: Paulus, P., Nijstad, B. (eds.): Group creativity: Innovation through collaboration. Oxford University Press, New York (2003) 32–62
19. McGrath, J.E.: Groups: Interaction and performance. Prentice-Hall, Englewood Cliffs, NJ (1984)
20. Janis, I.L.: Groupthink. Houghton Mifflin, Boston, MA (1982)
21. Ocker, R.J.: Influences on creativity in asynchronous virtual teams: a qualitative analysis of experimental teams. IEEE Transactions on Professional Communication 48 (2005) 22–39
22. Nickerson, R.S.: Enhancing creativity. In: Sternberg, R.J. (ed.): Handbook of creativity. Cambridge University Press, New York (1999) 392–430
23. Moscovici, S.: Social Influence I: Conformity and Social Control. In: Nemeth, C. (ed.): Social psychology: Classic and contemporary integrations. Rand McNally, Chicago, IL (1974)
24. West, M.A.: Reflexivity and work group effectiveness: A conceptual integration. In: West, M.A. (ed.): Handbook of work group psychology. Wiley, Chichester (1996) 555–579
25. Csikszentmihalyi, M.: Creativity: flow and the psychology of discovery and invention. HarperCollins, New York (1996)
26. Henry, J.: Creative Collaboration in Organisational Settings. Collaborative Creativity: Contemporary Perspectives (2004) 158–175
27. Hooker, C., Nakamura, J., Csikszentmihalyi, M.: The group as mentor: Social capital and the systems model of creativity. In: Paulus, P.B. and Nijstad, B.A. (eds.), Group Creativity: Innovation Through Collaboration. New York: Oxford University Press (2003)
28. Argote, L., Kane, A.: Learning from direct and indirect experience in organizations: The effects of experience content, timing, and distribution. In: Paulus, P.B. and Nijstad, B.A. (eds.) Group creativity: Innovation through collaboration. New York: Oxford University Press (2003) 277–303
29. Nijstad, B.A., Paulus, P.B.: Group creativity: Common themes and future directions. In: Paulus, P.B. and Nijstad, B.A. (eds.) Group creativity: Innovation through collaboration. New York: Oxford University Press (2003) 326–339
30. Bandura, A.: Guide for creating self-efficacy scales. In: Pajares, F., Urdan, T. (eds.): Self-efficacy beliefs of adolescents. Information Age Publishing, Greenwich, CT (2005)
31. Gough, H.G., Heilbrun, A.B.: Manual for the Adjective Check List. Palo Alto, CA: Consulting Psychologists Press (1965)
32. Eysenck, H.J.: Readings in extraversion-introversion. Staples Press, London (1970)
33. Wenger, E.: Communities of Practice: Learning, Meaning, and Identity. Cambridge University Press, Cambridge (1999)
34. Lawler, E.E., Hackman, J.R.: Impact of employee participation in the development of pay incentive plans: A field experiment. Journal of Applied Psychology 53 (1969) 467–471
35. West, M.A.: Innovation implementation in work teams. In: Paulus, P.B. and Nijstad, B.A. (eds.) Group Creativity: Innovation Through Collaboration. New York: Oxford University Press (2003) 245–276

36. Amabile, T.M., Conti, R., Coon, H., Lazenby, J., Herron, M.: Assessing the Work Environment for Creativity. The Academy of Management Journal 39 (1996) 1154–1184
37. Watson, C.B., Chemers, M.M., Preiser, N.: Collective efficacy: A multilevel analysis. Personality and Social Psychology Bulletin 27 (2001) 1057
38. Payne, R.: The effectiveness of research teams: A review. Manchester Business School, Manchester (1988)
39. Gibson, C.B., Randel, A.E., Earley, P.C.: Understanding group efficacy: An empirical test of multiple assessment methods. Group & Organization Management 25 (2000) 67